CARIES PREVALENCE IN ANCIENT EGYPTIANS AND NUBIANS

By

Konstantine Triambelas

RECOMMENDED:

Kara C. Hoover

Jamie L. Clark

Joel D. Irish
Advisory Committee Chair

David C. Koester
Chair, Department of Anthropology

APPROVED:

Todd L. Sherman
Dean, College of Liberal Arts

John C. Eichelberger
Dean of the Graduate School

8/15/14
Date

# CARIES PREVALENCE IN ANCIENT EGYPTIANS AND NUBIANS

A

THESIS

Presented to the Faculty

of the University of Alaska Fairbanks

in Partial Fulfillment of the Requirements

for the Degree of

MASTER OF ARTS

By

Konstantine Triambelas, B.A.

Fairbanks, Alaska

August 2014

Abstract

This thesis presents an expanded bioarchaeological perspective to quantitative analyses of dental caries in the remains of 1842 ancient Egyptians and Nubians. The skeletal samples from 17 Egyptian and 15 Nubian cemeteries are represented by both sexes, and span a period from 14000 BCE-1450 CE. Considering that a skeletal population of this size has never been previously evaluated for dental caries, this thesis can make a considerable contribution to a better understanding of the variability encountered in dental caries patterns over time, as these are manifested within the bio/cultural/ecological context of the Nile Valley.

Dental caries are the decomposition of tooth enamel resulting from the chemical breakdown of dietary carbohydrates by oral bacteria. In archaeological populations, increasing rates of dental caries have been positively correlated with consumption of agriculturally-based cereals such as wheat and barley. Dental caries rates thus provide a reliable indicator of human biocultural transitions to agriculture, as well as information on diet, general oral health, and social organization of the group. In the context of ancient Egypt and Nubia, dental caries frequencies have been previously used to evaluate regional variability in dietary practices, as well differential access to resources based on sex and social class/status.

This thesis reevaluates much of the above information using a larger and more statistically-representative sample. Quantitative analyses based on both non-parametric and parametric statistical techniques were used to assess intra- and inter-sample differences in mean tooth caries, mean individual caries, and mean ante mortem tooth loss (AMTL). These variables were compared across samples by region, time period, economic organization, sex, and social status. Results for Egypt were in agreement with previous research showing overall low caries prevalence increasing through time. Significant regional and inter-cemetery differences existed between Lower Egypt and Upper Egypt, as well as between late Dynastic samples and earlier ones. In Nubia, significant differences according to region and sex were shown to exist in the prehistoric/preagricultural component of the study. In contrast with previous findings, Nubian dental caries were higher in the earlier phases and declined during the agriculturally-intensive periods of later Nubian history. The exception to this last finding was the Christian period when both dental caries and AMTL experienced considerable increases.

## Table of Contents

List of Figures

List of Tables

# List of Appendices

## Acknowledgements

This work represents the cumulative influence, effort, and contribution of several individuals without whose assistance completion of this thesis would be impossible. First among them are the members of my master's committee Dr's. Joel D. Irish, Kara C. Hoover, and Jamie Clark. Dr. Irish's decades-long dedication and involvement in dental anthropology on the African continent provided the large set of data that allowed this thesis to materialize. Additionally, his guidance and deep knowledge has galvanized, hopefully, a future dental anthropologist in me. Dr. Hoover provided valuable input on the epidemiology of disease in past and present human populations, and Dr. Clark provided a much-needed archaeological perspective in the writing of this thesis. Thank you both for your comments, suggestions, and corrections.

Also, many thanks to other UAF anthropology graduate students in my cohort: Gerard, Laura, Clarissa, Fawn, Mike, David, Sarah, Meagan, you are already missed. I am also forever obliged to Charu and Brian at the UAF Anthropology Department's office for helping me successfully navigate the uncharted waters of departmental bureaucracy. Also, a big thank you to Juan, Hope, and Faith from UAF's Graduate School for all their help in matters of formatting and procedure. Last, but certainly not least, I would like to thank my important other, Ms. Vani Ari of San Francisco, CA, for her unending material and moral support in the difficult time that has elapsed between leaving UAF as a full-time student, and the completion of this thesis.

# CHAPTER 1

# PROLEGOMENON

## Introduction

Biological anthropology is an interdisciplinary biological and social science that seeks to understand and explain the complex biosocial, developmental, and evolutionary changes encountered in past and present humans, as well as their extinct relatives in the fossil record (Fuentes 2010). Central to bio-anthropological inquiry are issues that relate to past and present human diet, health, disease, reproduction, population size, and lifestyle, especially as these are shaped by the interaction of human culture, behavior, and the effects of the environment (Armelagos 2003, Armelagos and Van Gerven 2003).

Within this context, teeth become particularly important for several reasons. Teeth, unlike bone, do not remodel during a person's lifetime, and thus contain a better record of the physiological stresses experienced by the individual during the periods of growth and development (Larsen 2002). Further, because teeth are the only part of the skeleton that make direct contact with the world outside of an organism, they can provide an accurate record of that organism's interaction with its environment (Cuozzo and Sauther 2012). At the same time, teeth are the hardest elements in the human body. In particular, the enamel that forms the occlusal surface of teeth is almost as hard as topaz (Irish 2012, personal communication). Teeth thus tend to survive bone in archaeological assemblages and constitute the elements of the skeleton most likely to be found by the archaeologist/osteologist.

Because of these characteristics, information derived from the dental record can be used to address many evolutionary, biological, dietary, and behavioral questions that pertain to both ancient and modern human populations (Scott and Turner 1988). For example, variability in tooth size and morphology can be used to assess biological affinity among different human groups, as well as their extinct relatives (Garn et al. 1966, Harris and Bailit 1980, Turner II 1987, Lukacs and Hemphill 1993, Irish and Hemphill 2004, Hanihara and Ishida 2005, Irish et al. 2013). At the same time, teeth provide very useful indicators of past human diets. Because different foodstuffs alter the surface of teeth in distinct ways, analysis of macro- and microwear patterns can reveal information about the consistency and hardness of the foods consumed (Grine 1986, Hillson 1996). Additionally, isotopic analysis of the chemical 'signature' left in teeth (and bone) by naturally occurring elements can provide information about differences in consumption of marine versus terrestrial resources, or between C3 and C4 plants (Schwarcz and Schoeninger 1991, Ambrose et al. 2003).

Teeth are also good indicators of dental disease, and dental caries in particular. Because dental caries is one of the most commonly encountered pathologies in the archaeological record (Hillson 2001), information from teeth can be used to assess overall health and well being for the individual, human or otherwise. From an anthropological perspective dental caries is a very important pathology because of its antiquity and association with food production, especially the link between dental caries and consumption of carbohydrates from domesticated plants (Scott and Turner II 1988, Larsen 1996, 2002). Procurement, processing, and distribution of resources are associated with types of social organization and become influenced by labor division practices within the group (Larsen 2002). In stratified societies such practices are used to disseminate existing relationships of power and result in unequal distribution of resources (Schell 1997). Analysis of caries variability in past populations can be revealing of such contrasts, especially in regards to sex and social status differences in procurement and allocation of resources (Schoeninger 1979, Sillen and Kavanagh 1982, Schwarcz and Schoeninger 1991, Eaton et al. 2002, Ambrose et al. 2003).

The overall concern of this thesis is dental caries prevalence in ancient Egyptians and Nubians, and the implications dental caries may have entailed for the individuals in those populations. In the past, as well as the present, what, how, and when something was eaten were largely regulated by consumption practices related to religious or kinship affiliation, avoidance of taboos, sex and gender ascriptions, ethnicity, power and social status, bioavailability of resources, environmental fluctuations, and technological level (Parker Pearson 2003, Bettinger et al. 2007). On a group level, cultural events organized around the sharing of food, such as feasts, can be used to reinforce group cohesion and provide a structure for daily human activities, thus forming a 'homology of the daily fare' (Parker Pearson 2003, p 5). In this context observed dental caries frequencies on ancient teeth must be viewed as the end result of the sum of the physical, cultural, and ecological components that interact together in order to shape the epidemiology of dental caries in the particular population.

The way that the above factors came together to influence dental caries patterns in Egypt and Nubia created a dietary mosaic characterized by long-standing dietary conventions, e.g. the Dynastic Egyptian staples of bread and beer, or the Nubian use of cattle milk and blood as sources of animal protein. At the same time these conventions were coupled with pronounced regional dietary idiosyncrasy. In the Nile Valley, from the Mediterranean coast to Khartoum, dietary heterogeneity has been the rule, rather than the exception, for most of this region's history of human habitation. This was particularly true for the Late Paleolithic (21000-9000 BCE) and Neolithic (9000-4000 BCE) periods of Egyptian and Nubian prehistory. Lithic, ceramic, funerary, settlement pattern, and settlement size analyses indicate that during these periods the Nile Valley and adjacent western desert were inhabited by a number of human groups practicing a variety of subsistence strategies. These last can be thought of as human adaptive responses to the challenges presented by a variety of microenvironments, as well as increased climatic instability and environmental change (Clark 1971, Butzer 1976, Hassan 1980, 1986, Wendorf 1980a, Hays 1984, Ibrahim 1987, Caneva and Gautier 1994, Gatto 1997). Dietary variability appears to have been accompanied by differences in dental caries rates as well. Previous research on Egypto-Nubian dental disease, and dental caries in particular, indicates considerable dental caries differences between culturally related, contemporaneous and/or temporally adjacent groups (Hillson 1979, Ibrahim 1987, Beckett and Lovell 1994, Greene 2006).

This thesis is particularly suited to analysis of variability in dental caries frequencies for two reasons. First, this work draws heavily on the considerable research infrastructure that has been laid down by previous investigators of dental disease in ancient Egypt and Nubia. Due in part to the arid and desiccated climate that characterizes both regions today, Egypt and Nubia have produced some of the richest skeletal material anywhere in the world (Harris and Ponitz 1983). This material has been studied intensely from a bioarchaeological perspective, and much published research exists today on the skeletal and dental paleopathology of Egyptians and Nubians. A more thorough discussion of this subject takes place in Chapters Three (Caries) and Seven (Discussion). This body of existing research has assisted the writing of this thesis in a twofold direction: a) as a means of reference in the methodology and quantitative techniques used in dental caries analyses; and b) establishing a precedent for dental caries frequencies that can be used to measure the results of this analysis. Consequently one main research direction is comparative, e.g. contrasting thesis results to those from previous studies of dental disease in Egypt and Nubia.

It is expected that this comparative analysis will also lead to re-evaluation of existing information on dental caries in Egypt and Nubia. The dental caries data used in this thesis was collected by Dr. Joel D. Irish (Centre for Paleoecology and Evolutionary Anthropology, Liverpool John Moores University) as part of a larger project seeking to evaluate African biological affinities based on dental non-metric traits. The project is ongoing, has lasted for over 20 years, and has resulted, among other things, in the accumulation of a very extensive dental caries data set. Thus this thesis is in the unique place to be able to incorporate caries data from an unusually large and statistically robust skeletal sample. This is the second main reason for the thesis. Although several of the 32 samples in this study have been used, at one time or another, in other analyses of dental caries in Egypt and Nubia (see Chapter Seven), no previous investigator had dental caries data available on all cemeteries and at a single point in time. Thus the other research direction in this analysis is exploratory: the large data set can be used to pose anthropological questions that go beyond mere comparisons of caries frequencies between samples and address larger issues of biocultural evolution in the Nile Valley.

For example, this study includes a considerable sub-component of Nubian preagriculturalist hunter-gatherers. The five Nubian samples were excavated at different points in time. The first, from Jebel Sahaba in Lower Nubia, was excavated in 1968 (Wendorf 1968) while the most recent from Al Khiday in central Sudan was unearthed between 2005 and 2008 (Usai and Salvatori 2008). The compilation of dental caries information from these samples in a single, numerically robust data set allows for exploration of new questions pertaining to biocultural evolution around the time of the important transition to pastoralism and agriculture in Nubia and central Sudan. One possibility would be to explore patterns of inequality in distribution of resources among hunter-gatherers, as is discussed earlier in this section. Using a combination of comparative and exploratory approaches, this thesis is in good position not only to re-valuate what we already know about dental caries in Egypt and Nubia, but also outline new avenues of further research on the subject.

## Research Questions

The main research questions in this thesis have been formulated with all of the above in mind, e.g. they serve a combination of comparative and exploratory purposes. Overall emphasis is given to inter-sample comparisons of caries frequencies using statistical procedures available in SPSS v.19. Wherever applicable, results from dental caries comparisons are used to make broader inferences about diet, overall oral health, the ecological background, and the socio-economic organization of the populations represented by the samples. In relation to the latter, attention is given to inter-sample caries comparisons based on sex and social status. The research questions are as follows:

1) What are the overall temporal trends in caries frequencies that can be observed in the various phases of the cultural history in Egypt and Nubia? How do these results agree or disagree with previous research? Are there any significant new findings and how can they be explained within the bio/cultural/ecological context of the Nile Valley?

2) How do the results in this thesis compare to what has been published on caries differences between preagriculturalists and agriculturalists? Are there any caries patterns that can be observed among the preagriculturalist component? In particular, are there regional and/or sex differences between samples of hunters-gatherers-fishers ? How statistically significant are they, if at all, and how can they be interpreted in the context of what we know about the ecology of the agricultural transition in Egypt and Nubia?

3) How can inter-sample variability in caries rates contribute to our understanding of changes in dental caries patterns during the prolonged and culturally diverse Dynastic period in Egypt? Are there regional differences (i.e. Lower vs. Upper Egypt) and how can

they be explained in the context of what we know about ancient Egyptian diet and culture? Are there any changes in caries patterns in the later periods of Egyptian history, i.e. those that corresponded with increased population influx into Egypt? Considering the fact that social status information in this data set was only available for Egyptian samples, can caries comparisons based on status provide additional information on (expected) Dynastic variability in caries rates?

4) Finally, can we assess differential access to resources based on the caries findings in this analysis? Diet and nutrition are important components in the etiology of many diseases because a malnourished or undernourished individual presents a higher risk of exposure to disease, illness, and, eventually, death (Steckel et al. 2002, Greene 2006). At the same time, the type and quantity of food available are regulated by networks of social relations, income, and socioeconomic role of the individual (Thompson et al. 2004, Bernaby et al. 2009). Thus dental caries differences based on sex and social status can be indicators of inequalities in the availability of resources within the group (Greene 2006). Given these circumstances, can changing caries patterns between the two sexes provide information about the social organization of the various groups? For example, comparative ethnographic material indicates that sexual division in labor practices largely determines economic activities, as well as site type, in modern hunting and gathering groups (Haaland 1981). How significant is caries sex dimorphism in the Egypto-Nubian samples in this study and what can it tell us, if anything, about the economic roles played by members of the two sexes within their respective groups?

## Significance

The first systematic study of dental caries on ancient Egyptian teeth was compiled by Sir Armand Ruffer (1920). Although Egypto-Nubian dental anthropological studies have increased considerably since then, they remain relatively few compared to academic research on other skeletal pathologies skeletal pathologies suffered by Nile Valley inhabitants. Much of the existing dental pathology research in ancient Egypt have ben based on the Dynastic period, while, until recently, skeletal paleopathology studies included a limited number of Nubian samples.

Many of the previously published dental anthropological studies of Egyptian samples have produced highly variable, and sometimes conflicting, results. For example, Egyptian Dynastic rates for carious individuals can vary from a low of 10% reported by Hillson (1979) to a high of 42% reported by Mummery (1870), while the prevalence of carious teeth can range from a high of 8.7 % (Smith 1986) to an extreme low of 0.4% (Leek 1966). This variability in caries frequencies may have been partly due to the fact that observed long-term caries trends in Egypt have been highly dependent upon the samples being used (Rose et al. 1993). Since the skeletal populations for some of these studies were spatially and temporally restricted to a few cemeteries, it is likely that their results were sample-specific, i.e. tended to represent local dietary habits, not those of the population as a whole.

In contrast, the present dental caries study is unique both in scope and robustness. Observations for caries were made on 26,196 teeth belonging to 1842 individuals from 17

Egyptian and 15 Nubian cemeteries. The various samples span a period of almost 14000 years (12000 BCE-1350 CE), are of mixed affinity, sex, social status, and age, and thus constitute a cross-section of Egyptian and Nubian societies over

**Table 1.** Location and chronology of samples.

| Region | Cemetery | Time range | Period | n |
|---|---|---|---|---|
| Upper Egypt | Badari | 4400-4000 BCE | Neolithic | 40 |
| | Naqada | 4000-3200 BCE | Naqada I | 65 |
| | OK Hill | 1650-1550 BCE | Second Intermediate | 19 |
| | Hierankopolis | 3500-3,200 BCE | Naqada II | 248 |
| | Abydos Pred | 4,000-3200 BCE | Naqada I | 62 |
| | Abydos Old | 3000-2686 BCE | Early Dynastic | 54 |
| | Thebes | 2055-1773 BCE | Middle Kingdom | 54 |
| | HK27C | 2055-1650 BCE | Middle Kingdom | 47 |
| | Qurneh | 1295-1773 BCE | New Kingdom | 67 |
| | El-Hesa | 200-400 CE | Roman | 72 |
| | Kharga | 500-600 CE | Byzantine | 26 |
| Lower Egypt | Tarkhan | 3000-2890 BCE | Early Dynastic | 51 |
| | Saqqara | 2613-2494 BCE | Old Kingdom | 41 |
| | Lisht | 1985-1773 BCE | Middle Kingdom | 61 |
| | Giza | 664-332 BCE | Late Dynastic (Persian?) | 62 |
| | Saqqara/Manfalut | 332-30 BCE | Ptolemaic | 46 |
| | Hawara | 50-120 CE | Roman | 51 |
| **Total Egypt** | | | | 1066 |
| Upper Nubia | Al-Khiday Mesolithic | > 8255 BCE | Late Paleolithic/Mesolithic | 40 |
| | Al-Khiday Neolithic | 6650-6460 BCE | Neolithic | 25 |
| | R12 | 4800 BCE | Late Neolithic | 50 |
| | Kerma | 1750-1500 BCE | Kerma Classique | 63 |
| | Kawa | 2500-1750 BCE | Kerma Ancien/Moyen | 37 |
| | Soleb | 1550-1380 BCE | Pharaonic | 32 |
| | Kushite | 600 BCE-550 CE | Meroitic/Post-Meroitic | 63 |
| Lower Nubia | Jebel Sahaba | 12000 BCE | Late Paleolithic | 57 |
| | Gebel Ramlah | 5740-5555 BCE | Neolithic | 59 |
| | A-Group | 3,000 BCE | Late Neolithic | 52 |
| | C-Group | 2000-1650 BCE | C-Group | 62 |
| | Pharaonic | 1650-1350 BCE | Pharaonic | 38 |
| | Meroitic | 100 BCE-350 CE | Meroitic | 94 |
| | X-Group | 350-550 CE | X-Group | 63 |
| | Christian | 550-1350 CE | Christian | 41 |
| **Total Nubia** | | | | 776 |

a long period of time (Table One). Such a diverse skeletal population of this size has not been previously evaluated for dental caries. Additionally, 29 of the 32 samples (90.6%) in the current study numbered over 30 individuals. This number is significant in statistical analyses for reasons that are more thoroughly discussed in Chapter Five (Methods) below. For now it must suffice to say that the greater the sample size, the greater the probability becomes that statistical comparisons will produce valid results (Gravetter and Wallnau 2008, Kinnear and Gray 2010). The inclusion of a larger number of statistically robust samples makes this thesis particularly suited to analysis of inter-sample variability in dental caries, unlike many other archaeological populations that consist of only a few individuals.

Finally, the cemetery samples have a more or less balanced component of males and females. Comparisons among samples that differ greatly in size may produce results that are biased towards the sample with larger size (Field 2009). However, many factors can be involved and these are again discussed more thoroughly in Chapter Five. In this data set, only five of 32 samples (15.6%) are marked by one sex outnumbering the other by more than 50% (see Table Three in Materials). Considering that many of previous caries studies do not include information on caries frequencies by sex (see Rose et al. 1993) this study can make a considerable contribution to our understanding of sex differences in the allocation/consumption of resources.

Overall, this work is in position to provide a more detailed picture of both diachronic and synchronic patterns of dental caries in ancient Egypt and Sudan, as well as draw inferences on dental disease and oral health in general. The size and composition of the skeletal population also allows for posing broader biocultural questions such as the relationship between culture and environment, and the effect that these factors can have on observed patterns of dental pathologies (with a focus on dental caries). These issues are discussed in depth in Chapter Seven.

# CHAPTER 2

## THE LAND, CLIMATE, AND PEOPLE

Ancient Egypt was the land of the lower Nile Valley, reaching from the Mediterranean coast and the Delta in the north to the First Cataract at Aswan. Nubia originated in the Egyptian south and extended to the Fourth Cataract. Lower Nubia was located between the First and Second cataracts and is now completely submerged by Lake Nasser/Nubia (Hafsaas-Tsakos 2009). Upper Nubia extended farther to the south along the Nile, with the natural obstacles (granite outcrops and large islands) of the Fourth Cataract separating it from central Sudan (Hafsaas-Tsakos 2009). From an ecological perspective, the divide between Upper and Lower Nubia coincided with a change from a mainly desert environment to tall grass savanna and forest (Carlson and Van Gerven 1979, Bard 2008).

The Nile River is the longest river in the world and constitutes the most important geographical feature in northeast Africa. Its interminable course over the millennia has helped shape both the geomorphological features of the Nile Valley as well as human patterns of habitation and settlement along it. Technically, the Nile begins at Khartoum, the capital of modern Sudan, but its origin is found in its two main tributaries, the White Nile and the Blue Nile. The latter is fed by heavy rains in the Ethiopian highlands from June to September and contributes up to 80-85% in the Nile's total water volume. Besides the White Nile, another minor tributary is the Atbara River in eastern central Sudan (Bard 2008).

In its northward flow, the Nile has cut a deep riverbed in the soft sandstone substrate and has formed a seasonally inundated river valley of the convex variety. The latter accumulates primarily through bank overflow of suspended sediment and is marked by natural levees that rise above the seasonally inundated alluvial flats. In Predynastic times, and based on contemporary floodplain topography, these flood basins were three or four times larger than those observed today (Butzer 1976). The topography of levees and basins is bifurcated by numerous meanders, or wadis, that are built at a slower rate than the riverbed and thus come to lie below it. During each flood the river breaks out of its bed, disperses along the bifurcations, and in the process creates lagoons and lakes between levees that can retain water long after the river begins to recede in late October. Prehistoric inhabitants of the Nile Valey resided safely on the highest point on the levees, or the river banks, and used the rich alluvial basin after the flood to sow crops or graze their herds (Butzer 1959).

The importance of riverine resources in human exploitation patterns over time is stressed by the fact that most archaeological evidence from the period 15000-3000 BCE in Egypt is concentrated either within the (former) Nile floodplain or spring-fed oases, around the shores of lakes, along wadis, or other minor bodies of water such as ephemeral rain ponds (Butzer 1976, Marks 1991). In the western desert of Egypt (or eastern Libyan Desert) aggradation and deflation over geological time have resulted in a surface dotted with numerous pans and basins (Wendorf et al. 1976). The largest of these (Siwa, al Fayum, Farafra, Dakhla, and Kharga) provided large, semi-permanent bodies of water supplied by either the overflow of the Nile or groundwater sources. These locales have provided foci for human economic activities from the Paleolithic to the present day (Ibrahim 1987). Human habitation along the Nile and in the western desert has followed congregation and dispersion patterns that corresponded to the availability of riverine resources, as these were regulated by the ebbs and highs of the seasonal Nile floods and the climatic changes over time (Ibrahim 1987, Clark 1980). These are discussed in the following section.

## Climate and cultural change

Today Egypt is characterized by a warm, sunny, and almost rainless climate, with temperatures ranging from as low as 0° C (32° F) during cold winter nights to 40° C (104° F) in the daytime during summer. The temperature is generally cooler in the north but humidity is higher. The littoral zone along the Mediterranean coast also receives more annual rainfall, but this amount deceases rapidly as one moves inland. Cairo, which is situated at the heart of the Delta, receives just over one centimeter (cm) of rain (Ibrahim 1987). In Lower Nubia, the desert area on either side of the Nile between the Second and Dal Cataracts known as Batn el-Hajar ("Belly of Rocks") is one of the most barren and forbidding environments on earth (Van Gerven et al. 1995). During the dry season, this span of the river is reduced to a narrow stream punctuated by rocky outcrops and numerous islands, thus making navigation impossible (Bard 2008).

However, the conditions of aridity and desiccation that characterize the western desert of Egypt and Nubia today are relatively new and were not present until ca. 4800 BCE (Greene 2006). Prior to that the Nile Valley experienced several alterations between wet and dry cycles that, in turn, affected the highs and lows of the river's yearly flood cycle, and by extension the ecology of the riverine plain as a whole. During wetter episodes, i.e. during the Lower and Middle Paleolithic, rainfall was considerably more than today and supported open woodland, or moist to semi-arid environments, and numerous lake, springs, and other permanent or semi-permanent bodies of water (Wendorf et al. 1976, Wendorf 1980b).

A prolonged arid episode is evidenced in dune fossils ca. 90000 BCE for the last part of the Middle Paleolithic (Cremaschi and Di Lernia 1999). Although several wet episodes are also attested, increased aridity around this time lead to a depopulation of the western desert ca. 70000 BCE. From this time on, human habitation there was confined in the oases (Hendrickx and Vermeesch 2000, Bard 2008). Conditions of greater overall dryness punctuated by periods of increased rainfall continued into the end of the Upper Paleolithic ca. 21000 BCE. Increased aridity in the Nile's Ethiopian headwaters lead to severe down cutting in the Nile's bed by as much as 34 m (111.5 ft) in the Kom Ombo region of Upper Egypt, and the overall climate during this time was most likely as hot as it is today (Butzer 1980, p 266).

The Late (Terminal ) Paleolithic that began ca. 21000 BCE was characterized by the greater overall climatic variability that marked the transition into the warmer, post-glacial environment of the Holocene (Hassan 1997a). Increased rainfall and wetter conditions between 18000-15000 BCE are evidenced in the aggradation of the Ballanas-Masmas formation in Nubia, during which the Nile reached as high as 25 m (82 ft) above its modern floodplain (Wendorf and Schild 1976). In the succeeding Deir el-Fakuri interval of intense aridity and deflation (ca. 15000-13000 BCE), Sudanese Nile levels may have been decreased by as much as 16 m (52.4 ft) (Street and Grove 1976, Wendorf and Schild 1976, Clark 1980). Climatic instability intensified towards the end of the Pleistocene and evidence from Nilotic bed gravel shoals provide support for Hassan's (1980, 1986, 1997a) hypothesis for exceptionally high and catastrophic Nile floods around this time. Their disruptive effect on human subsistence patterns is evidenced, among other things, by the decrease in number of archaeological sites, a greater reliance on aquatic resources, and the elimination of stylistic traditions in pottery decoration (Hassan 1980). Ultimately, the environmental instability that characterized the Pleisto-Holocene transition in the Nile Valley may have led to a greater reliance on fishing and exploitation of wild cereals, and may have even precipitated cattle domestication during the succeeding Neolithic period (Hassan 1980, 1986).

In Egypt, the beginning of the Neolithic coincided with a northward drift of the monsoonal rain belt by as much as 600-700 km (Wendorf et al. 1992). Playa (ancient lake) sediments from Egypt's western desert indicate that there was a period of increased rainfall ca. 9100-6800 BCE, with as much as 200 -300 mm/annum of rain in the southern region and 50-100 mm in the north (Wendorf and Hassan 1980, Hassan 1986). Riverine sediments also attest to another major Nilotic aggredation by as much as 10 m above present-day levels in Nubia (Küper and Kröpelin 2006). The pluvial conditions in the Nile Valley during the early Neolithic created the ecological basis for a 'greening' of the eastern Sahara that allowed humans to re-occupy the western desert of Egypt for the first time since the Mesolithic (Wendorf 1980a). A shifting of human habitation patterns westwards during this time is exemplified by the fact that there is almost a complete lack of settlements in the Egyptian Nile Valley, with the notable exception of El Kab (Kuper and Kröpelin 2006). A severely arid interval for the period ca. 6800-5480 BCE was followed by overall moist conditions that lasted until 3300 BCE, which roughly corresponds to the beginning of modern day arid conditions in Egypt and Nubia (Wendorf and Hassan 1980, Smith 1998). After 4900 BCE what is now the western desert became less inhabited in a gradual process that lasted until around 4400 BCE. After that, human occupation of the western desert practically ceased except in the major oases such as Kharga and Dakhla (Hendrickx and Vermeesch 2000). Geoarchaeological evidence from Wadi Bakht indicates quantitatively less amount of rainfall even in the highlands of Gilf Kebir by 4120 BCE (Linstädter and Kröpelin 2004).

Environmental instability and increased aridity may have set the ecological background for the adaptive responses that led to animal and plant domestication and, ultimately, the emergence of complex society in Egypt. Migratory movements from the Sinai, the Negev, and the western desert towards the heartland of the Nile Valley may have laid the population basis for an autonomous change towards domestication of plants and animals as means of securing additional resources, or stabilizing the economic base (Hassan 1984, 1997c).

## Archaeology and cultural history

The course of archaeological inquiry in a riverine plain such as that formed by the Nile Valley is greatly affected by geo-hydrological processes of sedimentation, alluviation, erosion, and deflation. Changes in the Nile's course over time, floodplain aggradation, and intense human activity and settlement guaranteed that many archaeological sites were irrevocably disturbed, or buried under heavy layers of alluvium (Butzer 1960, Wenke 1989, Bard 2008). This reality is reflected in the many Neolithic and Predynastic cemeteries that were found without accompanying settlements to account for the burial population. The apparent lack of settlements is most likely due to the fact that ancient Egyptians selected to bury their people in the low desert margin edge (and thus away from the flood zone), while their settlements were situated in the adjusted floodplain and are now probably lost for ever (Patch 2004). Scarcity of settlement sites is a recurring issue in Egyptian and Nubian archaeology and it must be taken into account when interpreting cemetery data.

## The Paleolithic

The Terminal Paleolithic (21000-9000 BCE) in the Nile Valley was marked by considerable changes in lithic technology and a widening of dietary breadth when compared to previous periods. During this period, microblade techniques in stone tool making became widespread. Several lithic industries used the same basic bladelet technology but great variability existed on a local level in use of different tool types. Such variability suggests seasonal or specialized activities, most probably organized around fishing and the hunting of large game (Clark 1971, 1980, Hassan 1980). One of the longest-lived lithic industries was the Qadan (13000-4500 BCE) in Lower Nubia. Qadan cultures also produced cemeteries with identifiable elements of mortuary ritual, such as in body placement and the inclusion of burial offerings. These may indicate a more stable social group with established territory and recurring subsistence patterns (Clark 1980).

Grinding stones were found in large numbers in sites ranging from the Second Cataract in Lower Nubia to Kom Ombo in Upper Egypt and indicated an increase in the exploitation of wild grains and cereals (Wendorf and Schild 1984). Grinding equipment found at the Kom Ombo site of Khor el Sil II (type-site of the Silsilian lithic industry) had been dated as early as 15000 BCE (Clark 1971). At the same time, fishing activities in the Terminal Paleolithic were expanded to include deep-water fishing in the main channel of the river during the low flood season in summer (Wetterstrom 1993a, 1997, Van Peer et al. 2003). Overall, these hunting and foraging tactics represented an adaptive shift away from the Mesolithic reliance on the hunting of large game, precipitated by the warmer climate. Grain utilization may have provided the nutritional basis for the expansion of the population indicated by settlement and cemeteries sizes; this in turn may have resulted in increased conflict and competition for resources, as evidenced in the violent deaths of individuals from Site 117 in Jebel Sahaba, Lower Nubia (Hasan 1980, Bard 2008). Ultimately, between 15000-9000 BCE the Nile Valley was frequented by multiple, distinct cultural groups, who employed different systems of procurement in order to exploit a diverse ecological setting characterized by several unique microenvironments (Clark 1971, Wendorf et al. 1976).

## The Neolithic

The Neolithic period features fundamentally different human exploitation strategies and cultural innovations compared to the previous Paleolithic. Neolithic Egyptians and Nubians used pottery to cook food, lived in permanent or semi-permanent settlements with houses, cultivated wild cereals such as sorghum, and managed domestic animals such as cattle, sheep, and goats (Wendorf et al. 1976, Wendorf and Schild 2001). The process leading up to these important biocultural changes was not uniform, was influenced by the alternating wet/dry episodes that characterized most of Holocene paleoclimate, and varied significantly on a local level. Generally, Upper Paleolithic traditions lasted longer in Nubia, for the Neolithic did not commense until 5000 BCE (Geus 1991). Even then, human groups in central Sudan continued with a greater reliance on hunted game and domestic cattle than contemporaneous groups in Egypt. Because of the diversity in Neolithic adaptative strategies, this period must be addressed in separate sections. These sections have been organized according the geographic region: the western desert of Egypt, the Fayum and Lower Egypt, the Upper Nile Valley, and Nubia respectively.

### The Neolithic in the western desert (9000-4700 BCE)

As was briefly stated earlier, the pluvial conditions during the early Holocene were conducive to the reoccupation of the oases and other areas of the western desert by Neolithic Egyptians. All archaeological remains of the semi-permanent and permanent hamlets, and/or villages, from this period were found exclusively in association with water environments such as the shores of playas, banks of wadis, in oases, and around elevated semi-permanet bodies of water (Wendorf 1980a). The earliest Neolithic sites, such as those excavated at Bir Kiseiba and Nabta Playa, were small, short term hunting-gathering camps with no evidence for sedentism (Wendorf et al. 1976). At some point, the same hunter-gatherer-fisher groups began employing techniques of management of wild herds that eventually lead to the domestication of cattle, sheep, and goats.

Animal domestication is one of the greatest issues concerning Africanist archaeology and falls outside the scope of this thesis. Analyses of sequence variations in bovine mtDNA showed that all modern haplogroups (including the African T1) represented subsets of the haplogroup found originally in the Near East. These studies lend strong support to the latter locale as the domestication centre for *B. taurus* (Stock and Gifford-Gonzalez 2013). However archaeofaunal (Gautier 1984) as well as more recent Y-chromosome data have provided some evidence for genetic contribution of regional wild males into the domesticated African cattle population (Achilli et al. 2009, Linseele 2010, Gifford-Gonzalez 2013). In northern Africa, the earliest conclusively domesticated *Bos* remains come from the Acacus Mountains of southwestern Libya and are dated between 5947-4986 BCE (Smith 1984a). It is plausible that pastoralist practices entered the Egyptian western desert from areas of incipient cattle domestication further west in Chad, Mali, Niger, the Acacus Mountains, or, alternatively, from the Near East. In the latter scenario, hybridization between native wild and domestic cattle may have taken place. Pastoralist practices most likely developed as an adaptive response by hunters/collectors/fishers to the deteriorating climatic conditions and environmental instability that characterized the Middle and Terminal Neolithic in those areas (Smith 1984a, Van der Veen 1995, Hassan 2000, Barich 2002).

In any case, early remains of presumably domesticated cattle from Nabta Playa were found at site E-74-6 and dated to 6250 BCE (Wendorf et al. 1976, Wendorf and Hassan 1980). Nearby site E-75-8 produced charcoal layers that contained ovicaprid remains with a date of ca. 6000 BCE (Wendorf and Schild 2001). Although the progenitor of African sheep/goat originated in souteastern Asia (Wetterstrom 1993a, Wendorf and Schild 1994, Close 2002, Kuper and Kröpellin 2006), evidence for their presence at Nabta Playa indicates that domestic ovicaprids may have entered Africa from an east-west route across the Red Sea and eastern Egypt. This conclusion has been partially supported by finds of caprine remains in Sodmein Cave on the Red Sea hills ca. 6000 BCE, as well as evidence for developed pastoralist economy in the Sinai during this time (Close 2002).

The Neolithic inhabitants of the western desert also display a greater reliance on the exploitation of wild cereals than their Paleolithic predecessors, and may have practiced, or at least attempted, some management of wild crops. Neolithic sites at Nabta yield large collections of edible plant remains representing 127 different species including sorghum, several varieties of millet, legumes, rhizomes, tubers, and fruit stones. Although none of these has been identified as domestic, infrared spectroscopy of lipids in sorghum seeds indicated some affinity with the domesticated variety (*S. bicolor*). The changes observed in Neolithic sorghum suggests that the latter might have been cultivated while remaining genetically wild (Wendorf et al. 1992, Wendorf and Schild 2001).

Numerous grass grains have also been identified at Neolithic sites in Farafra oasis, roughly 500 km (311 mi) north-east of Nabta. The fossilized remains included members of the genera *Panicum*, *Echinocloa*, *Brachiaria*, *Pennisetum*, and *Sorghum* (Barakat and Fahmy 1999). The inhabitants of Farafra used bifacial tools as sickles and axes for tilling the soil, and the manufacturing technique had affinities with similar tools found at Baharia oasis to the north and Siwa to the northwest (Barich 1993, 2002). On the basis of these finds one can assume that intense exploitation of wild cereals, and/or incipient horticulturalism, were practiced throughout the western desert thousands of years before domesticated barley and emmer wheat agriculture appeared in Lower Egypt (Wasylikowa and Dahlberg 1999). This equally important innovation is discussed in the following section.

## The Neolithic of Lower Egypt

In Lower Egypt, around the Fayum and the Delta, the Neolithic period is divided into an earlier Epipaleolithic, or Fayum 'B' (ca. 7050 BCE), period and a later 'proper' Neolithic, of Fayum 'A'.  Fayum 'B' sites are characterized by the small, backed bladelets of the Qarunian industry and are contemporaneous to the Nabta occupations in the western desert. However, Qarunian sites are small, fishing camps that lack pottery, cereal exploitation, or traces of organized settlements (Wenke et al. 1988). An occupational hiatus of 1200 years separates the Qarunian sites from later Neolithic horizons (Clark 1980). This temporal gap may be related to a severe drop in lake levels between 6000-5100 BCE that forced the last inhabitants elsewhere, perhaps towards the Nile Valley (Hassan 1986). When human occupation resumed at Fayum ca. 5500 BCE (Bard 2008) the material culture was different than the Qarunian assemblage, particularly in the frequencies of types of flaked stone tools, and the presence of pottery and many grindstones.

These differences suggest that the Fayum Neolithic (5450-4400 BCE) was most likely intrusive into the area (Wenke et al. 1988, Wenke and Casini 1989, Hendrickx and Vermeesch 2000). The origin of the Neolithic Fayumians is still under debate, but some possible locations include the Great Sand Sea to the west (Wendorf and Schild 1994), north Africa and the Maghreb (Butzer 1976), the Egyptian western desert (Hassan 1986), and Palestine. Even though Fayum A sites contain remains of domesticated emmer wheat, six-row barley, sheep, and goats with unquestioned Near Eastern origins, the stone tools bear many similarities to lithic industries from the western desert (Hendrickx and Vermeesch 2000). At the same time, the frequencies of faunal remains from Fayum A indicate that an ovicaprid economy was not as important to these people as it had been for the innovators of caprine domestication in southeast Asia (Wenke et al. 1988). Overall, archaeological data point to a north African origin of the Fayum Neolithic, albeit with significant technological and cultural influences from southwestern Asia (Hendrickx and Vermeesch 2000, Bard 2008).

Regardless of these important dietary and economic innovations the Neolithic Fayumians still lacked the trappings of a fully-fledged agricultural economy. The latter were encountered for the first time in NE Africa at the archaeological sites of Merimde Beni-Seleme (5000-4100 BCE), located near the apex of the Delta, and El Omari (4600-4350 BCE) located just south of modern day Cairo. Merimde is a complex site with multiple occupational levels and an economy based on emmer wheat (*Triticum dicoccum*) and flax agriculture, and animal husbandry (sheep, cattle, and pig), supplemented with some fishing and hunting (Hendrickx and Vermeesch 2000). Substantial mud-walled, partly subterranean dwellings, granaries, and cemeteries in Merimde and El Omari point to formalized, village-type economies with considerable trade and exchange links to the Sinai and Palestine (Wenke 1989).

**The Neolithic of Badari (Upper Egypt)**

The Neolithic transition and related agricultural adaptations in the middle Nile Valley have been most extensively documented in the area of Badari-Matmar-Mostagedda-Hamamiyeh, 30 km (18.6 mi) south of the modern town of Asyut (Hassan 1988). As is the case with Merimde and El Omari, the Badarian culture (4400-4000 BCE) is mainly known from cemeteries in the low desert. Mortuary evidence reveals that Badarian peoples practiced farming and animal husbandry supplemented by fishing and some hunting. Cultigens at Badarian sites includ emmer wheat, six-row barley, lentils, flax, and tubers of *Cyperus* (nutsedge), while the animal component of the economy consisted of domestic cattle, sheep, and goat (Hassan 1988, Bard 2008). Badarian settlements consist of pole-thatched constructions associated with hearths, grain silos of plastered straw and basketry, and pen-like animal enclosures coated in layers of sheep and goat droppings (Hassan 1988, Wenke 1989). The thin layer of material deposits and the small overall area of Badarian settlements suggest that these latter were short-lived and most likely functioned as temporary, seasonal camps (Hassan 1988, Hendrickx and Vermeesch 2000).

Based on funerary goods and rituals, Badarian burials are the first to attest to a level of social complexity previously unseen in the Saharan Neolithic, or that of northern Egypt (Bard 2008). Although Badarian burials have very few goods, they include elaborate items of personal adornment such as bracelets, hairpins, and beads made of ivory, seashell, and bone (Hassan 1988, Hendrickx and Vermeesch 2000, Bard 2008). If one accepts the premise that mortuary ritual reflects social position during life, then these burials pose obvious implications for some differentiation based on social status within Badarian society. Additionally, the presence of exotic materials such as ivory, seashell, and copper in Badarian burials implies the existence of long-distance trade networks to Nubia and sub-Saharan Africa, the Rea Sea coast, and the Sinai (Hendrickx and Vermeesch 2000). The incipient tendency towards social stratification observed in Badarian cultures was accelerated in the succeeding Predynastic period. The latter was characterized by the appearance of a funerary cult associated with imported luxury goods, the rise of commercial town elites, craft specialization and, ultimately, centralized kingdoms in Egypt.

## The Naqada period (or Predynastic, 4200-3200 BCE)

Predynastic Egyptians utilized stone tool technology and thus essentially they remained a Neolithic culture. However they differed greatly from previous Neolithic Egyptians in social complexity, economic practices, and social organization. From an archaeological perspective the Predynastic period is synonymous with the Naqada culture in Upper Egypt. Naqada is located on the left bank of the Nile's Qena bend and was excavated extensively by Sir Flinders Petrie in the 1930s. The latter was also largely responsible for the typology and seriation of the many pottery finds at Naqada. After minor alterations, the dating scheme he established is still used today to describe the chronology of the Predynastic period (Bard 2008).

Pottery styles and burial practices during the Nagada I, or Amratian, (4200-3500 BCE) differed little from the preceding Badarian and the former is generally considered a southward continuation of the previous cultural phase (Midant-Reynes 2000, Greene 2006). However, in Amratian burials wooden coffins are used for the first time and there is a greater diversity in grave goods and offerings. The latter includes elaborate items of personal adornment that were absent from Badarian burials, such as disc-shaped maceheads and cosmetic pallets made of greywacke and stone (Midant-Reynes 2000, Greene 2006). These tendencies towards increased complexity in mortuary ritual were greatly accelerated in Naqada II (or Gerzean, 3500-3200 BCE ) and Naqada III (aka 'Dynasty 0', 3200-3000 BCE). The late Naqada II Cemetery T contained larger, brick-lined tombs with decorated walls, is geographically isolated from the rest of the burial population, and contains exotic materials such as faience and lapis lazuli (Bard 1989).

This complex pattern of grave differentiation has not been observed previously and implies that the people buried at Cemetry T represented a political or economic elite (Bard 1989, 1994, 2008). It is likely that mortuary ritual complexity paralleled other developments towards a greater degree of hierarchization in society. The increase in trade and exchange of luxury goods observed in Naqada II and Naqada III may have given rise to commercial elites that in turn stipulated an increasingly complex network of funerary beliefs, ritual, and architecture as a means of power legitimization and social aggrandizement (Bard 1989, 1994). The prestige of the first chiefs, or elites, may have been further bolstered by their managerial role in mitigating unforeseen difficulties in agricultural production, and by their organizational role in addressing ritual and supernatural beliefs associated with agricultural life (Hassan 1988).

In any case, Naqadan burials experienced a marked decrease in burial goods during the Naqada III period. The richest Naqada III tomb at Naqada was still richer than the poorer burials of the same horizon, but paled in comparison to contemporary burials at nearby Hierankopolis and Abydos (Bard 1989). In the former, recent excavations at cemetery HK6 revealed impressive rectangular burial chambers equipped with thatched superstructures, painted enclosure walls, and associated offering chapels. Importantly, the burial chambers were abutted by colonnaded, aboveground structures that had no clear association with tombs (Friedman 2008). This part of the cemetery was also marked by animal burials on three of its four sides. Based on the location of the cemetery and the prestige objects found within (including stone statuary), it was suggested that this area may have represented a 'holy' precinct for the burial of a ruler, or other important person, as well as the veneration of ancestor's cult (Friedman 2006). Thus by middle Naqada II, Hierankopolitan cemeteries had already acquired vestiges of subsequent Early Dynastic and Dynastic mortuary complexes. It was also during this time that Naqada II wares replaced Bhuto and Ma'adi ceramics in Lower Egypt (Bard 2008).

Settlement size, investment of labor, and wealth of mortuary goods suggest that Hierankopolis during this time constituted a regional center, or capital, under the rule of a chieftain, or most likely, regional king (Friedman 2006, 2008). The existence of powerful local rulers prior to the unification of Upper and Lower Egypt (ca. 3000 BCE) is also attested by impressive elite and/or royal mortuary architecture at Abydos. The early Naqada III tomb U-j had a subterranean, triple-course mud brick wall and consisted of twelve rooms covering an overall area of 66.4 sq m (715 sq ft). Tomb contains included many luxury items of bone and ivory, 400 imported wine jars from Palestine, as well as 150 small, inscribed labels that represented the earliest known form of hieroglyphs (Adams 1996, Bard 2000). It thus appears that from the beginning ancient Egyptian writing developed in a context of increased social complexity and political centralization (Bard 2008). Other tombs at cemetery U contained gold, silver, lapis lazuli, ivory, obsidian, carnelian, as well as a whole wooden bed with carved bull's feet (Bard 2000). Such unprecedented wealth (for Egyptian standards) indicated that by 3200 BCE Upper Egypt at least was under unified control most likely stemming from the rulers at Abydos.

## The Neolithic in Nubia and Sudan

Contemporary populations in Sudanese Nubia appear to have continued a traditional way of life long after the arrival of pottery and cattle domestication and no significant break occurred with previous stone technologies (Haaland 1977, 1995, Clark 1980). In central Sudan, Late Paleolithic deposits are virtually unknown and the Mesolithic continued until the onset of the Khartoum Neolithic, ca. 5000 BCE. The Early Khartoum period, or Khartoum Mesolithic, is characterized by the introduction of pottery in the area of Sudan for the first time as early as 9400 BCE (Hassan 1988). Mesolithic Sudanese lived in a greener and more seasonal environment than today. Precipitation at the junction of the Nile and the Atbara rivers in the Mesolithic may have reached 400-500 mm annually (Peters 1993). Overall pluvial conditions were also reflected in the wide variety of fresh-water resources harvested by Mesolithic Atbarans. These included land and freshwater snails, water mollusks, bivalves, reptiles, soft and hard-shelled turtles, and several species of aquatic birds (Caneva and Gautier 1994). Like their Egyptian counterparts around this time, they also invested heavily on fishing. The importance of the latter is demonstrated by the great species diversity of fish bone samples and the variety of cultural implements associated with fishing activities found at Mesolithic Sudanese sites. Ichthyofaunal assemblages from three Mesolithic Atbaran sites dated 7650-5720 BCE include at least 22 species and 17 genera of Nilotic fish, and all Early Khartoum sites have yielded bone harpoons and disc-shaped pottery sinkers. Fishing nets and baskets were also likely to have been used but the perishable material they were made of (presumably fiber twine) has not survived in the archaeological record

(Van Neer 1989, Haaland and Magid 1992). Moreover, presence of flood plain dwellers together with deep-water fish in bone assemblages indicate that Mesolithic Atbarans harvested this protein-rich resource year round (Peters 1991, 1993).

The transition from late Khartoum Mesolithic into Khartoum Neolithic took place around 5000 BCE with the introduction of thinner pottery vessels, surface burnishing, and the gradual growth of triangular and lined impressions as vessel decorations (Marks 1991). Lithic technology and subsistence changed very little between the two periods, the most radical difference being the introduction of domesticated cattle and sheep/goat husbandry between 3500-3200 BCE (Clark 1971, 1980). The presence of thousands of fragments of worn out grindstones at Neolithic Kadero (5280-5030 BCE), located north of modern Khartoum, suggests regular consumption of processed grains on a considerable scale, including wild cereals (together with sorghum), and grasses (Krzyzaniak 1991).

A major differentiation of the Khartoum Neolithic compared to the previous Mesolithic period occurred with the introduction of more elaborate burial customs during the former. For example, funerary goods recovered in fourth millennium BCE burials from the central-Sudanese cemetery at El Kadada include female pottery figurines, dog and goat skeletons, and bucrania. Comparative analysis of burial pits also indicated human sacrifice in those tombs containing three bodies or more (Geus 1991). The presence of human sacrifice and deposition of bucrania become widespread in later times, and particularly during the Classic Kerma phase of the First Kushite kingdom. The increased complexity of the graves and their grouping in clusters at this early point in time may reflect a non-egalitarian society showing incipient elements of social differentiation (Geus 1991).

**Table 2.** Nubian chronology.

| |
|---|
| Terminal Paleolithic 21000-12000 BCE |
| Khartum Mesolithic 12000-5000 BCE |
| Khartum Neolithic 5000-2800 BCE |
| A-Group 3400-24000 BCE |
| C-Group 2200-1460 BCE |

The closing millennia of the Neolithic witnessed the growth of the A-Group culture (3400-2400 BCE) in Lower Nubia. A-Group pottery bears stylistic and technological similarities to the Abkan assemblages from central Sudan and is thus considered an indigenous outgrowth of the Nubian/Sudanese Neolithic cultures further upstream (Clark 1980, Hays 1984, Martin et al. 1984). A-Group sites differ from the preceding Neolithic in several distinct ways. A-Group people were incipient agriculturalists who practiced a semi-nomadic lifestyle that combined millet agriculture with husbandry of domesticated cattle and goats (Beckett and Lovell 1994). Other cultural A-Group innovations compared to the Neolithic include semi-permanent houses with stone foundation slabs (Bard 2008), and differentiated burial wealth indicated some social inequality (Becket and Lovell 1994). Additionally, the A-Group peoples established extensive trade relationships with predynastic Egypt but also central Sudan, Syro-Palestine, and the western deserts (Gatto 1997). Towards the terminal A-Group phase the wealth and quantity of imported items, mainly from Egypt, had so increased as to indicate a social organization at the level of chiefdom or principality, several of which may have existed at key points along the Nile at Dakka, Seyala, and Qustul (Smith 1991, O'Connor 1991). The Neolithic in Lower Nubia came to an abrupt end ca. 3000 BCE with the gradual disappearance of A-Group sites. The reasons for this are under debate but it is likely that the demise of the A-Group was due to Egyptian military intervention in Lower Nubia during the First Dynasty (3000-2890 BCE). This intervention allowed the centralized Egyptian state to assert greater control of the trade routes in imported luxury goods, and especially gold (Trigger 1976, Smith 1984b, Bonnet 1991, Shaw 2000, Bard 2008).

## Egypt and Nubia in historical times

Insofar, this chapter has been concerned with a review of the archaeology, ecology, and cultural history in the Nile Valley during the Paleolithic and Neolithic periods. The latter included the Qarunian culture in Lower Egypt, the Badarian and Naqada cultures in Upper Egypt, and the A-Group peoples in Lower Nubia. Unification of Egypt into a single country represents a significant point in the history of both Egypt and Nubia. From this time on the two polities began to follow distinct but interconnected paths, in a way that one could not address the history of Egypt without references to Nubia, or vice versa. This section of the chapter attempts to do just that: present a short history from early Dynastic to Christian times in Nubia that focuses on the most significant point of interaction between the two countries.

For most part, Egyptian foreign policy towards Nubia can be seen as a systematic attempt over time for control of the lucrative and culturally significant trade goods associated with the complex rituals of Egyptian mortuary cults. During times of Egyptian ascendancy these attempts took the form of open military intervention, i.e. the campaigns of New Kingdom kings against the serious territorial and commercial threat posed by the kingdom of Kerma in central Sudan. On the other hand, Nubia took in, transformed, reinvented, and reframed Egyptian influences, while retaining both regional identity and a unique course of cultural development through time (Smith 1998). This fact is archaeologically evident by the distinct Nubian mortuary, architectural, and artistic traditions that persisted even during times of direct Egyptian control (Hafsaas-Tsakos 2009).

As was discussed earlier in this chapter, Egypt was unified into a single country by early Dynastic kings ca. 3000 BCE, or slightly before. This process was lengthy and most likely extended over a period of 250 years, or 10 to 12 human generations (Hassan 1997b). Unification may have involved warfare and was preceded by expansion of Upper Egyptian cultural traits into Lower Egypt, as well as consolidation of political, regional, and economic power in Upper Egypt into a single polity centered on Abydos (Hassan 1997b, Bard 2000, 2008). At the same time, centralized power depended on the crown's ability to assert its ideo-political role as the main agent in the dispersal of agricultural and luxury goods to the appropriate segments in Egyptian society (Bard 1989, 1992, Hassan 1997b). During the turmoil that must have accompanied the years of unification, this ability may have come under threat by more assertive A-Group chiefs in Lower Nubia. A likely scenario is suggested by the early record for a military victory in Nubia by Aha, the very first king of the First Dynasty, ca. 3000 BCE (Hassan 1997b). More campaigns are recorded under his successor king Djer and it is likely that by 2700 BCE Egyptian control along the Nile extended to the Second Cataract at Buhen (Adam 1981). A-Group burials ceased in Lower Nubia after this time and it is likely that the inhabitants relocated to areas further away from Egyptian control. However, the situation in Lower Nubia was likely far more complex than indicated by the archaeological record: for if the area had been abandoned as it appeared archaeologically, there would have been no reason for the Egyptians to repeatedly fortify their southernmost city on Elephantine Island (Williams 1997).

During the reign of the six Dynasties (Third-Eighth) that comprised the Old Kingdom period (2686-2125 BCE), Egypt experienced a long and uninterrupted period of economic prosperity and political stability, in continuation of the Early Dynastic period. It rapidly grew into a hierarchical, centralized state ruled by a king believed to be endowed with qualified supernatural powers, and administered by a literate elite selected at least partially on merit (Wenke 1989, Malek 2000). The enormous, impressive, and unparalleled pyramids of the Fourth Dynasty at Giza demonstrated both the ideological significance of kingship in Egyptian society, as well as the Egyptian state's ability to successfully meet enormous organizational and logistical demands. Agricultural techniques during this period did not change much and relied on artificial irrigation with limited land management, as before. The role of the state consisted in regulatory and organizational actions in order to prevent famines with better distribution of food, lessen the effect of environmental calamities, and eliminate local conflicts through arbitration, thereby improving overall security (Malek 2000, Bard 2008).

Towards the end of the Old Kingdom central authority in Egypt seems to have collapsed over a period that lasted approximately from 2184-2160 BCE. The causes were most likely to be found in a combination of ecological, economic, and political factors. A period of exceptionally low floods from 2900-2200 BCE, in combination with an increasing population after 3000 BCE, laid the ecological and demographic basis for repeated food shortages, even famine (Butzer 1976). At the same time, there were reduced resources available during this period and the crown could not mediate to counter these upheavals as effectively as before (Bard 2008). The succeeding First Intermediate period (2160-2055 BCE) was characterized by an increase in the power of the provincial aristocracy and governors, and a polarization of royal power between two competing centers in Heracleopolis (near the Delta) and Thebes (Upper Egypt). After struggles that must have lasted a few generations, the Theban kings of the 11$^{th}$ Dynasty (2125-1985 BCE) unified the country after what appears to have been a violent and destructive military campaign to the north (Seidlmayer 2000). During the following Middle Kingdom (2055-1660 BCE) period political unity and central authority were restored, and there was an increase in economic prosperity and all forms of art.

In the years of the discontinuous events associated with the First Intermediate period, Lower Nubia was reoccupied by agro-pastoralist groups that were culturally and biologically related to the previous A-Group people (Carlson and Van Gerven 1977, Adam 1981, Martin et al. 1984, Johnson and Lovell 1995, Irish 2005, Irish and

Konigsberg 2007). During the later phases in their development, these C-Group cultures (2200-1850 BCE) built impressive burial superstructures and were most likely organized into hierarchical, powerful chiefdoms in control of Nilotic trade routes to and from Egypt (Bard 2008). These latter may have roughly corresponded to the Old Kingdom Egyptian toponyms of Warwat, Irtjet, and Setju (O'Connor 1991).

Important cultural and political developments took place during this time in Upper Nubia as well. Historiographical evidence embedded in Old Kingdom literary texts indicated that by the Fifth Dynasty (2494-2345 BCE) pastoral and mixed economy groups in the Dongola region of Upper Nubia had coalesced around at least one important chiefdom in the area of Kerma (Trigger 1976, O'Connor 1991). Thus the Early Kerma culture and the C-Group developed simultaneously on temporally overlapping horizons, but with different styles in pottery and burial superstructures (Bonnet 1991). By the end of the Middle Kingdom in Egypt (Middle Kerma), Kerma had developed into a centralized, stratified state ruled by a powerful trading elite and/or a king. Accumulation of considerable wealth at Kerma was due to state control over the lucrative trade in luxury goods with Egypt, especially gold, as well as the manufacture of valuable commodities (Smith 1998).

It is likely that the gradually increasing control of Kerma over the vital trade routes with sub-Saharan Africa precipitated the developments leading to the collapse of the Middle Kingdom in Egypt ca. 1685 BCE. During the Second Intermediate period (1650-1550 BCE), Kerma grew into a large kingdom with several subject rulers, encompassing an area from Aswan in Egypt to central Sudan. The kings of Kerma were able to erect grandiose palatial and temple mudbrick architecture, mobilized armies against Upper Egypt, and built impressive tumuli tombs accompanied by human and animal sacrifices (O'Connor 1991, Davies 2003, Bard 2008). The Second Intermediate period represented a particular time of crisis in Egyptian history, since this was the first time that the country experienced considerable territorial encroachments from foreign powers. In the north of Egypt, the Delta had been occupied by Western Asians who ruled from their newfound capital at Tell el-Dab'a (Avaris). These people, known as Hyksos, were called *Aamu* by ancient Egyptians, and were most likely economic immigrants or prisoners of war brought into the Delta from the Levant during the Middle Kingdom (Bourriau 2000). Severely constrained in both a northerly and southerly direction, Egyptian rule during this time was confined to a narrow belt in Middle Egypt. Egyptian kings abandoned the 12$^{th}$ Dynasty capital at Itjtawy in favor of Thebes far to the south- and further away from the threatening Hyksos (Bourriau 1991).

Egyptian fortunes were reversed with the unification of the country under the early New Kingdom (1550-1069 BCE) pharaohs. Ahmose I (1550-1525 BCE) defeated the Hyksos, conquered Avaris, and immediately set against Kerma in Nubia (Bard 2008). Egyptian military operations over the next 30 years culminated in the capture and sack of Kerma by forces of Thutmose I (1504-1492 BCE). Direct imperial Egyptian control in Upper Nubia reached to the area of Kawa, with the region between there and the Fifth Cataract under the control of subject or allied rulers (Morkot 1991). Egyptians solidified control of the region with the establishment of many temple/fortress towns such as those at Soleb and Amarna. Egyptian settlers also moved south and most likely combined with local inhabitants. Principal component analysis of nine craniometric traits from Tombos, near Kerma, indicated that most of the inhabitants at that time can be identified as ethnic Egyptians, but with a good degree of hybridization between Egyptians and local Nubians (Buzon 2006).

The Ptolemaic and Roman periods in Egyptian history coincided with another period of Nubian ascendancy, first under the Napatan kings (750-300 BCE) and later during the Meroitic empire (350 BCE-300 CE) in central Sudan. Napatan commercial elites most likely benefited by the introduction of the camel and the new possibilities the latter offered for trade caravans across the western desert. These developments undermined Egyptian monopoly of trade routes to the Near East and initiated a center-periphery shift in favor of the Napatan state (Smith 1998). Napatan rulers adopted Egyptian cosmology, cultural symbols, and mortuary ritual, and eventually came to rule Egypt as the pharaohs of the 25$^{th}$ Dynasty (Smith 1998, Bard 2008). Napata developed into an important religious center and retained its cultic significance even later when the center of Kushite power shifted upstream to Meroe (Bard 2008). Meroitic economy was based on intensive cultivation of emmer wheat and barley but a third, summer crop was introduced with the domestication of sorghum. These innovations resulted in an increase of cultivable land and population size (Martin et al. 1984). The Meroites eventually had to cede control of Lower Nubia to the military super-power of Rome and a well-supplied Roman fort was established at Qasr Ibrim, north of Abu Simbel. From there, the Romans moved upstream eventually capturing and sacking the religious center of Napata (Wilkins et al. 2006, Bard 2008). Meroitic power seems to have waned for the same reason that contributed to its ascent: control of trade routes. Numerous Red Sea ports established in Ptolemaic and Roman times ultimately undermined Meroitic role as mediators in the trade of exotic raw materials with India and the Far East (Bard 2008). The end of the Meroitic period is characterized by decentralization and population fission with several autonomous centers appearing under the X-Group (350-550 CE). By the latter part of the sixth century CE Nubia had completed conversion to Christianity, brought into the country from neighboring Egypt. Christian Nubia (550-1500 CE) was a conglomeration of semi-independents rulers and came into increasing pressure from neighboring Islamic polities, including Fatimid Egypt. The end of Christian Nubia came in 1323 CE when a Muslim prince, supported by Mameluk Egypt, ascended to the Nubian throne (Martin et al. 1984).

In conclusion, Chapter Two is an attempt at presenting a concise review of the ecology, archaeology, and cultural history of Egypt and Nubia in the time periods covered by the samples in this study. Ecological and climactic changes affect bioavailability of resources and greatly impact patterns of human subsistence and diet. Changing climate and diet over time can thus indirectly affect rates of dental disease, and those of caries in particular. At the same time procurement and consumption of goods are regulated by practices relating to ethnic, personal, or religious beliefs. Understanding the cultural and ecological context in which food consumption takes place can thus be important in the interpretation of changes in patterns of dental disease over time. This chapter also provided useful references for the discussion on dental caries that takes place in Chapters Three (below) and Seven.

# CHAPTER 3

# DENTAL CARIES

## Introduction

As was mentioned earlier, the study of disease in past human populations is one of the main goals of bioarchaeology as a sub-discipline of physical anthropology. Diseases caused by infectious agents, such as dental caries, have had profound effects on health throughout human evolutionary history. In demographic terms, infectious diseases have caused more deaths than all wars, noninfectious diseases, and natural disasters taken together (Inhorn and Brown 1990). Because of its impact on differential mortality and fertility rates, disease has been an important force of natural selection, shaping both human biology and culture (Haldane 1949, Inhorn and Brown 1990, Brown et al. 1996, Schell 1997). Dental caries is one of the most commonly recognized diseases in archaeological populations (Matovich 2002, Greene 2006, Hillson 2008).

As such, dental caries, together with periodontal disease, constitute an important component of both oral and general health. Poor dental health can have serious overall consequences for the well being of individuals through both localized and systemic effects. Prolonged and untreated exposure to caries can lead to pulp infections, gingival inflammation, abscessing, and multiple tooth loss. These conditions promote poor nutrition through reduction of masticatory efficiency and a corresponding decrease in food intake (Powell 1985). In modern human populations, dental caries is widespread in children and subadults in general. In the US, dental caries is five times more common than asthma and affects approximately 28% of children (Palmer et al. 2010). Other studies suggest that carious children have significantly poorer oral health-related quality of life, increased absences from school, and higher risk for hospitalization (Sheiham 2006). Additionally, adult studies in the US have demonstrated a relationship between oral health and systemic diseases such as cardiovascular ailments, diabetes mellitus, osteoporosis, and rheumatoid arthritis (DeWitt and Bekvalac 2010).

Some other studies point to a functional relationship between dental caries and undernourishment. The latter represents chronic stress that could expose the individual to a higher risk for disease, illness, and eventual death. For example maternal deficiency in minerals and micronutrients, such as iron, folic acid, Vitamin B-12, Vitamin D, and zinc, has been associated with poor pregnancy outcomes, increased potential for caries in children, low birth weights, and heightened risk for immunological diseases in early childhood (Allen 2005). Nutritional content of the ingested foods is thus associated both with increased susceptibility to the deleterious effects of disease, as well as the negative effects the disease process can have on growth, development, and longevity of the individual (Steckel et al. 2002). Diet is also the primary mechanism for the net increase in the oral bacteria that contribute to dental caries. The latter is the result of the accumulation of acidic byproducts from the chemical breakdown of dietary carbohydrates, especially sugars, in the human mouth (Gustafsson et al. 1954, Hillson 1979, 2000, 2008, Navia 1994, Larsen 1997, Lingstrom et al. 2000, Touger-Decker and van Loveren 2003, Petersen and Lennon 2004, Greene 2006, Selwitz et al. 2007, DeWitt and Bekvalac 2010).

The close correlation between dental caries and the carbohydrate component in diet constitutes caries rates as the most telling indicator of dietary shifts in past human populations. In broad terms, the bioarchaeological record indicates an increase in dental caries frequencies during the transition of human populations from hunting-gathering-fishing to an agricultural lifestyle. Strong, positive correlations between dental caries frequencies and consumption of soft, carbohydrate-rich cereals and grains has been demonstrated for several Old World (Leek 1966 and1972a, Greene 1972, Hillson 1979, Lukacs 1992, Rose et al. 1993, Matovich 2002, Greene 2006) as well as New World (Leigh 1925, Stewart 1931, Knutson 1975, Swanson 1976, Millner 1984, Schneider 1986, Larsen et al. 1991, Larsen 1997, 2002, Hillson 2008) skeletal populations. Nevertheless there are studies that have produced some contradictory results. Turner II (1978) found no caries among the early agriculturalists from the Valdivian culture (ca. 2000 BCE) of coastal Ecuador, while comparisons between Mesolithic and Neolithic samples showed that the transition to an agricultural economy in Britain was not followed by a corresponding increase in dental caries rates (Chamberlain and Witkin 2003).

Additionally, several studies indicated lower caries frequencies in southeastern Asian agriculturalists subsisting on a rice-based diet. Caries comparisons between early cultivators and later, full-scale rice agriculturalists (ca. 2000 BCE-500 CE) from Thailand showed small and statistically insignificant dental caries differences (Tayles et al. 2000). Modern studies that compared urban and rural Thai children showed that the latter had significantly less caries, primarily because their diet still consists of rice-based dishes. Rice is naturally low in sugars, and when it is coarsely prepared, it tends to not adhere to teeth while stimulating salivary flow, which has a cleansing effect in the oral environment (Techanitiswad 1994, Kedjarune et al. 1997). Other studies compared relative cariogenicity of different cereals in children from 47 countries and found that milled rice did not correlate with dental caries. On the contrary, wheat flour had a strong and positive correlation with dental caries (Screebny 1983). As things stand, rice and its cariogenic potential fall outside the scope of this thesis. The latter is primarily concerned with agricultural populations who consumed a diet based on emmer wheat and barley, with sorghum also playing a lesser but important role. Although dental caries levels provide a useful indicator of the carbohydrate component in the diet, at least when the latter is derived from wheat and barley, skeletal populations must be assessed for dental caries individually and by taking into account the respective cultural and ecological context.

## Dental caries pathology

Caries is derived from the Latin term for ‘rottenness’ (Powell 1985). Dental caries can be defined as localized and progressive destruction (demineralization) of dental enamel, dentine, and cement by organic acids produced through the fermentation of oral fluids and dietary carbohydrates by some categories of oral bacteria (Van Houte 1980, Sheiham 1983, Larsen 1997, Hillson 2000, 2005, Palmer et al. 2010). Carious lesions develop differently, depending on the location of the carious lesion on the surface of the tooth.

Coronal lesions are initiated in the enamel of the crown surface, or in dentine exposed by wear, and can be further subdivided into occlusal and smooth surface caries. The occlusal surfaces of human molars and premolars are characterized by systems of pits and fissures that are particularly susceptible to caries (Hillson 2005). In modern human populations, the site most at risk for caries attack is the occlusal fissure system of the permanent first molars, together with the buccal pit, or depression, of the lower first molars (Hillson 2008). Smooth surfaces on teeth are defined as the sides of the tooth crown, outside the fissures or pits of the occlusal surface, and not bordering the cervical margin (Hillson 1996). Approximal, or interproximal, smooth surface caries is the second most prevalent, with lesions occurring on the mesial and distal crown surfaces where adjacent teeth come into contact with each other (Hillson 2001, 2008).

Compared to occlusal caries, interproximal lesions tend to increase with age in both archaeological and living human populations (Moore and Corbett 1971, Turner II 1978, Molnar and Molnar 1985, Manji et al. 1989, 1991, Lubell et al. 1994, Hillson 2008). In some populations, there are statistically significant differences in older adult interproximal caries rates between the maxilla and the mandible, with the former exhibiting higher disease rates (Vodanovic et al. 2005). In archaeological populations, increased levels of tooth wear in older individuals may have a) eliminated carious occlusal surfaces and/or b) indicated greater masticatory loads that could have resulted to greater mesial drift and a widening of the interstitial spaces between teeth (Powell 1985).

Other smooth surface caries can be initiated on the buccal and lingual sides of the crown, just above the line of the gingival border (Hillson 2001). Buccal and lingual caries often fail to develop in populations with alveolar bone loss because, with age, the gingival attachment recedes and exposes the area to greater natural cleaning. Irrespectively of alveolar bone loss, the lingual side of tooth crowns is subject to the cleansing action of the tongue at all times (Hillson 1996).

Root caries lesions occur along the cemento-enamel junction (CEJ) at the base of the tooth crown, or on the cement that covers the supragingival root margin. Root caries are secondary to exposure of the gingival margin and/or the tooth root by continuous tooth eruption or accelerated rates of alveolar bone loss, secondary to periodintis and/or periodontal disease (Hillson 2000, 2001, 2005). Since the severity for both of these mechanisms is time-dependent, in archaeological populations root caries tend to become predominant caries type in older adult groups that may also be experiencing higher rates of dental wear and gritty, abrasive diet (Moore and Corbett 1971, Meiklejohn et al. 1988, Caglar et al. 2007).

The development of carious lesions on teeth occurs gradually. Chronic caries develops through alternating episodes of stable (arrested) or active (progressive) states, depending on the combined action of the various etiological factors involved in caries formation-these are elaborated later in this section (Matovich 2002, Hillson 2005). Carious lesions begin as microscopic brown or white opaque spots, become dark, pigmented, and visible to the naked eye, and eventually cause cavitation and formation of a necrotic pit below the enamel surface (Hillson 1996, 2005). Once the cavity (whether on enamel, root, or cement) reaches the enamel-dentine junction (EDJ), it spreads into the underlying dentine layer. Even at this point, the carious lesion may not penetrate the pulp, and the tooth enamel may remain stable for years, or even remineralize, depending on etiology and odontoblastic secretion rates of secondary, reparative dentine (Hillson 1996 and 2001). However, if the lesion remains untreated, the pulp will be penetrated and exposed to infection. This is a very painful stage of the disease and for most of human history thus far the only sure remedy has been extraction of the tooth: consequently caries, together with periodontal disease, constitutes the most common cause for ante-mortem tooth loss (AMTL) in archaeological populations (Lukacs 1996, Hillson 2006).

## Histology of human teeth

In order to better understand the epidemiology and etiology of caries, knowledge of basic tooth histology is necessary. The mouth of the developing human embryo is covered by ectodermal epithelial cells that will eventually become ameloblasts (enamel-building cells). On the other side of what will become the enamel-dentine junction (EDJ), mesenchymal cells derived from the mesodermal germ layer congregate together in order to form the dental papilla. Dental papilla cells differentiate into odontoblasts (dentine-building cells) and begin to secrete predentine, whereas other mesenchymal cells form a bag-like structure (dental follicle) that will ultimately form the root socket. Once predentine secretion is initiated, ectodermal cells on the other side of the epithelial border differentiate into ameloblasts and initiate the enamel-building process (Hillson 1996). Enamel is composed of 96% inorganic material, consisting almost entirely of calcium and phosphate minerals in the form of apatite. Apatite crystals can also contain other minor calcium phosphates such as whitlockite and brushite (Hillson 2005).

Enamel is laid down in an incremental manner beginning at the cusps and continuing towards the tooth apex (Guatelli-Steinberg 2008, Ritzman et al. 2008). Ameloblast cells deposit the apatite crystals that form the enamel in successive layers organized into rod-like bundles called *prisms*. Enamel prisms run parallel to each other at an approximate angle of 120° to the crown surface. Under scanning electron microscopy enamel prisms appear as regularly spaced lines separated by thin zones of discontinuity, which are made of interprismatic enamel (Hillson 2005). Enamel prisms are interspersed by regular, alternate swellings and constrictions that are usually spaced out at 2-6 μm along the prism length (Goodman and Rose 1990). Looked at from a distance, the swellings form *cross striations* that interject the enamel prisms at 90° in regular intervals; thus the appearance of the enamel surface at close magnification resembles a square-shaped honeycomb (Hillson 2005, Fig. 2.3). This apparatus is in turn crossed in a diagonal direction by a coarser layering of enamel called *brown striae of Retzius*. Brown striae are regularly spaced along the occlusal half of the crown but they become irregular and harder to discern near the cervix. Counts of the cross-striations between brown striae can provide estimates in the periodicity of the latter, with an average of eight days for modern humans and apes (Hillson 1996, Dean and Reid 2001, Guatelli-Steinberg 2008).

Dentine is similarly laid in a crystalline matrix by dentine cells (odontoblasts) lining the sides of the pulp chamber. From there, odontoblast processes branch out surrounded by closely spaced tunnels called *dentinal tubules.* These extend towards the dentine and cementum borders in a tapering fashion, reaching a diameter of 7-8 μm near the end (Hillson 2006). The space between tubules is occupied by a meshwork of collagenous material embedded in a calcified ground substance, while some areas of the intertubular space remain incompletely calcified (Knutson 1975). As a result, dentine is not as hard as enamel and possesses a mineral/organic composite structure made of 75% inorganic by dry weight, 18% collagen, and 2% other organic material. In a way similar to that of enamel, dentine formation begins at the cusp tips and proceeds downwards in a series of sloping, sleeve-like layers with a space in the middle provided for the pulp chamber and the root canal (Hillson 2005).

While enamel does not remodel once formed, odontoblast cells can continue to secrete dentinal matrix throughout life in situations where the pulpal chamber is threatened with exposure. Secondary dentine is 8% harder than regular dentine and is deposited in a way that exposed dentinal tubules are sealed up at the pulp by secondary dentine patches (Hillson 1996). In addition to its reparative role, secondary dentine formation is a natural physiological process that accelerates with age as the pulp cavity begins to fill.

## Dental caries etiology

The human mouth is host to a wide variety of bacteria that colonize the soft tissues within a few hours from birth. The appearance of teeth provides stable, non-shedding surfaces on which oral bacteria use to build microbial communities that are known as dental plaque (Hillson 1996). Oral bacteria bind to the tooth surface, and to each other, by synthesizing extracellular polysaccharides, such as glucan, and interacting with amino acids and glycoproteins found in human saliva and gingival crevice fluid

(Van Houte 1980, 1994, Hillson 1996). The resulting plaque matrix is strongly structured with a definite surface membrane into which nutrients diffuse selectively. Empty spaces in the matrix are occupied by the plaque fluid, which is a combination of dissolved gasses, sugars, amino acids, and the organic acids produced by fermentation, especially lactic acid (Hillson 1996 and 2008).

The acidogenicity of the plaque matrix is determined to a large extent by the amount of carbohydrates in the diet. Sugars are the most important of those and their presence in the diet is directly related to a positive increase in the mass of plaque matrix and its main manufacturer, *Streptococcus mutans* (van Houte 1994, Hillson 2008). Plaque bacteria are dominated by gram-positive streptococci such as *S. mutans* but also include gram-positive rods, such as *Actinomyces* and *Lactobacillus*, gram-negative cocci (*Neisseria* and *Veilonella*) and rods, as well as treponemal bacteria of the genus *Spirochetes* (Swanson 1976, Hillson 2005, Rudney et al. 2005). Mutant streptococci and lactobacilli, except some 'low pH' non-mutant streptococci, were the only organisms among plaque microbiota who have been shown to exhibit positive correlation with caries activity in rats (Michalek et al. 1977). Demineralization of the tooth surface takes place during acidic episodes that lower the pH in the mouth below the critical level of 5.5 (van Houte 1980, Duggal 1991). Prolonged acidic episodes, such as with frequent consumption of carbohydrates, seem to favor oral bacteria adapted to highly acidic environments and low pH levels, such as *S. mutants* and *Lactobacilli*. These latter are able to process sugars rapidly, produce acid rapidly, and continue their metabolic functions under conditions of acidity few other bacteria could tolerate (Hillson 1996).

Acidic byproducts reinforce the acidic component of the plaque fluid matrix, which initiates dissolution of the enamel substrate. Once carious lesions appear, the cavity site provides an ecological niche in which plaque organisms adapt to a permanent state of reduced pH (Selwitz et al. 2007).

The process of enamel demineralization also depends on the variable action of decay-arresting factors, such as saliva and level of fluoride in drinking water. Saliva is rich in calcium and phosphates and can act as a natural buffer to cariogenic activity and assist tooth re-mineralization. Additionally, saliva washes away cariogenic substances from teeth and increases the alkaline content in the mouth (Van Houte 1980). Experiments with mice that had their salivary glands removed and were fed a high sucrose diet showed significantly higher caries activity compared to the control group with regular salivation (Schwartz and Weisberger 1955). In humans, the condition of xerostomia, or ‘dry mouth’, is also associated with higher caries rates (Brown et al. 1976). Thus consistency and flow of saliva is an important regulating factor in plaque pH and caries activity. Fluoride ions are naturally occurring and are present in drinking water and some foods (Hillson 2005). Fluoride becomes incorporated into teeth and bones and low-level concentrations of it can confer some protection against caries. Communities that practiced water fluoridization showed 50%-70% less caries (Leverett 1982) and Hildebolt and co-workers (1989) have shown that the degree of variation in caries prevalence in the State of Missouri was associated with the geochemically defined divisions within the state. Studies of caries prevalence in past human populations should, whenever possible, incorporate evidence of fluoride concentrations in alluvial and lacustrine deposits.

Dental caries susceptibility is also influenced by host-specific genetic factors. Longitudinal twin studies analyzing surface-based caries rates suggest 40-65% heritability in caries variance among young children (Bretz et al. 2005). Other studies provide evidence that polymorphisms of the *beta defensin 1* (DEFB1) gene are associated with high and low caries experience haplotypes. Defensins are peptides that constitute key elements of the innate immune system. Beta defensins are the most widely distributed defensins in the human autoimmune system and are secreted in biological fluids such as saliva and gingival crevicular fluid (Ozturk et al. 2010). Base substitutions of the DEFB1 marker rs179946 can produce a high-caries experience haplotype (GCA), which increases carious teeth two-fold. A low-caries experience haplotype (ACG) in the same promoter region can also exist, decreasing carious teeth two fold. The GCA and ACG haplotypes comprised approximately 70% of the studied population, which makes these haplotypes suitable markers for future studies in the epidemiology of dental caries (Ozturk et al. 2010).

Thus the etiology of caries can be viewed as an integrated and incompletely understood system where oral bacteria, morphology of teeth, diet, saliva, genetic and environmental factors interact constantly to alter the pH levels in the mouth, in turn facilitating or inhibiting development of caries. Regular and frequent consumption of carbohydrates is the most important factor in making a sustained shift in the balance between tooth mineral content and plaque fluid toward net mineral loss (Hillson 1996).

As noted above, some exceptions to this general rule are also encountered in the archaeological record, especially in relation to consumption of rice in agriculturally based Asian populations.

## Carbohydrates and dental caries

Dietary carbohydrates can be divided into simple and complex, (Lingstrom et al. 2000). Among the simple carbohydrates (sugars), sucrose has the highest cariogenic potential in modern human populations, followed by glucose and fructose (Sheiham 1983, Hillson 2008). In western diets sugars, and especially sucrose, are readily available from a very young age and this in turn has considerable epidemiological implications: in the US dental caries is one of the most common childhood pathologies, being five times more common than asthma and seven times more common than hay fever (Touger-Decker and van Loveren 2003, Selwitz et al. 2007). Sucrose has a special caries-promoting role because it is a specific substrate for glucosyl transferase, the enzyme in mutant streptococci strains responsible for the synthesis of extracellular polysaccharide glucans (Navia 1994). The latter, as has been discussed, are a major adhesive for the plaque matrix.

The relationship between carbohydrate consumption and increased caries rates was unequivocally established during and after the Second World War (WWII) in countries, like Britain and Japan, which experienced sugar rationing. Dental caries prevalence in those countries dropped dramatically during WWII, only to increase in postwar years when sugar, and sucrose, became available again (Takeuchi 1962, Sheiham

1983). In continental postwar Europe generous importation of refined sugar from the Caribbean islands amounted to a virtual caries epidemic in children, especially in countries, like the Netherlands, that did not practice water fluoridation at the time (Touger-Decker and Van Loveren 2003).

The response of government health agencies in many western countries was increased funding for research in the etiology of dental caries. Several studies generated during that period offered important information in the relationship between sugars and caries. For example, it was established that among sugar-consuming subjects the highest frequencies of dental caries occurred in those individuals who consumed the stickiest types of sugary foods multiple times throughout the day (Gustafson et al. 1954). Other studies suggested that dental caries activity was not influenced by the total amount of sugars ingested, as long as they were not consumed in-between regular meals: the latter helped to retain lower pH plaque values for longer periods of time and thus exacerbated the enamel decomposition that naturally took place during meal times (Zita et al. 1959). Thus where sugar is concerned, caries prevalence can be considered the outcome of both net sugar intake and the frequency of *in-between* meal sugary snacks. In modern human populations the latter very often come in the form of sugary drinks and sticky, candy-like products (Newbrun 1982).

Unlike the unequivocal connection between increased sugar consumption and higher caries rates, the relationship of the latter to starches is more ambivalent. Studies of the cariogenicity of cereal diets in cotton rats showed that the teeth of the animals fed corn flakes were extensively carious, while those of the animals fed whole oats showed little decay. Such results suggested that whole grains were less cariogenic than processed cereals (Constant et al. 1952). Starches are polymers of glucose enclosed within starch granules that vary in shape and size (Lingstrom et al. 2000). During food preparation starch granules are affected by heat and mechanical forces and undergo a process of transformation. Rupture and eventual disintegration of the granules releases the starch molecules in a process called gelatinization (Lingstrom et al. 2000). Gelatinized starches that enter the human mouth are liable to hydrolysis by salivary and bacterial amylases and conversion into the sugars glucose and maltose (Mormann and Muhlemann 1981). Plaque bacteria can readily ferment glucose and maltose but the bioavailability of the latter in the human mouth is closely associated with the process of gelatinization. For example, when wheat flour is subjected to increasingly severe processing conditions an increasing plaque acidogenicity is induced in the following order: steam flaked < dry-autoclaved < < extrusion cooked < drum-dried < popped wheat (Lingstrom et al. 2000).

Such experiments established that an important exogenous factor in the cariogenecity of starches is food preparation, processing, and cooking method, such that extensive processing and cooking at high temperatures tends to increase the bioavailabity of caries-promoting, starch-derived sugars in the human mouth. The importance of culturally mediated food preparation techniques in caries prevalence can be demonstrated in the archaeological population of Pueblo Amerindians from Gran Quivira, New Mexico (1315-1672 CE). The Pueblo diet consisted primarily of beans, maize, squash and amaranth. Preparation techniques for these cultigens included parching, toasting, boiling, and baking, while seeds were ground into flour for use in mush, breads, or cakes. All of these methods resulted in a loosening of the fiber content of the plant material. The softened fibers produced a sticky foodstuff that adhered to the tooth surface and interproximal areas after eating, making them more prone to caries attack (Swanson 1976). Statistically significant differences in carious lesions per individual as a result of food processing techniques were observed in two Basketmaker and post-Basketmaker samples from southwestern Colorado (Schollmeyer and Turner II 2004). According to these researchers, the significantly higher prevalence of interproximal caries in the former sample can be attributed to grinding techniques that produced a finer-textured flour than in the post-Basketmaker sample. The fine texture of the flour increased stickiness thereby increasing retention of elements of the bolus in the interproximal spaces between adjacent teeth (Schollmeyer and Turner II 2004). Additionally, studies with rats indicated a possibility for caries-enhancing interaction between starches and sugars. Firestone et al. (1984) found that cooked wheat starch was less cariogenic than sucrose but that a mixture of the two was more cariogenic than either of them alone. These data suggest that starches can serve as a ‘co-cariogen’ by promoting longer retention of sugar on teeth, and contributing to marked pH depression secondary to prolonged acidic episodes (Hillson 1996, Lingstrom et al. 2000).

## Dental caries in archaeological populations

Dental caries can be considered a truly ancient pathology. Possible carious lesions have been described on the teeth of herbivorous dinosaurs from the Cretaceous (55-120 million years ago, Moodie 1948). In anthropoids, Moodie (1923) described an unconfirmed case of dental caries in primates from the Bridger Eocene (45-70 mya) of Wyoming. In the same work, the author also described several cases of Pleistocene caries, i.e. on the tusk of an individual mastodont of the species *M. obscurus*. In extinct hominins, caries has been observed on the teeth of South African *A. africanus* and those of the archaic *Homo sapiens* from Broken Hill (Clement 1958). In a general sense, caries rates in humans remained low through the Paleolithic, Mesolithic, and Neolithic, increased with the transition of various human groups to agriculture, and rose rapidly from the Medieval through to the modern period (Hillson 1996, 2008). Because of the close association of caries with dietary carbohydrates (discussed in previous section), increasing caries rates is the single most telling biological indicator for the transition from a hunting-gathering lifestyle to sedentism and agriculture (Larsen 2006). Turner II (1979) calculated increasing average caries prevalence for world populations at 1.7% for foragers, 4.4% for mixed forager-agriculturalists, and 8.6% for intensive agriculturalists.

In the Old World, support for Turner II's (1979) results came from caries rates comparisons between pre-agricultural and agricultural populations from the Indian subcontinent (Lukacs 1992), the Levant (Smith et al. 1984, Eshed et al. 2006), and Scotland (Lunt 1974). In the New World caries prevalence provided a marker for the shift from foraging to maize agriculture. Overall, there is a tendency for prehistoric and early contact-era maize farmers to have higher caries prevalence than prehistoric foragers. This trend was demonstrated in comparisons from the Georgia Bight and the Florida coast (Larsen et al. 1991, Larsen et al. 2002, Larsen et al. 2007), prehistoric Amerindians from

Ohio (Schneider 1986) and Illinois (Milner 1984), prehistoric North American groups of diverse tribal affiliation (Leigh 1925, Knutson 1975), pre-contact and early contact Southwestern skeletal series from Gran Quivira (Swanson 1976), pre-contact Peruvians (Stewart 1931), and Classical Maya (Cucina et al. 2012). Furthermore, marked increases in dental disease took place in modern Alaskan native groups that, until recently, retained their traditional subsistence practices and only switched to a western-style diet within the last 30-40 years (Mayhall 1970, Costa Jr. 1980). In Africa, modern ethnographic research provided evidence for increased caries prevalence in Bantu horticulturalists from Zaire and the Central African Republic when these were compared to neighboring hunting and foraging pygmy groups (Walker and Hewlett 1990).

**Sex and dental caries**

Analyses of prehistoric and historic caries rates in human populations showed that, overall, females suffered more frequently than males (Lukacs and Thompson 2008). This sex dimorphism in caries rates was accentuated with the adoption and intensification of agriculture (Larsen et al. 1991, Lukacs 1996). The anthropological and clinical literature on the causes of sex differences in dental health offers two broad areas of interpretation, behavioral and physiological (Larsen et al. 1991). Traditional anthropological explanations for sexual dimorphism in dental caries tend to favor behavioral factors such as sexual division of labor and women's domestic role in food production (Lukacs and Largaespada 2006).

In a well-known study, Larsen and coworkers (1991) examined patterns of dental health and lifestyle in a temporally diverse sample of Guale groups from the Georgia Bight (the coastal area along the modern border of Georgia and Florida). The dental sample represented various stages of biocultural adaptation for these groups, beginning with pre-contact, pre-agriculturalists (1000 BCE-1150 CE) and extending to late contact agriculturalists (1686-1702 CE). The authors detected significant sex differences in percentage of teeth affected per tooth class for all periods. They attributed this to differential consumption of maize, with males consuming a relative smaller proportion than their female counterparts. Maize contains a significant amount of sucrose (2-6%) and increased maize reliance from the late prehistoric period onwards can be considered the main reason for the accelerated caries rates through time in the Georgia Bight (Larsen et al. 1991). Because of their role as primary food preparers, Guale females experienced increased exposure to cariogenetic risk both through greater overall consumption and greater periodicity in consumption (snacking). As has been discussed previously, frequency of starch intake is an important factor in cariogenesis. Repeated and frequent snacking on carbohydrate-rich foods tends to extend the acidic episodes of low oral PH and thus increase rate of enamel demineralization. This factor may explain in part the difference in caries prevalence between males and females reported for Georgia Bight (Larsen et al. 1991).

In her comparative analysis of diet and health between two Predynastic Egyptian samples from Hierankopolis and Naqada, Greene (2006) detected statistically significant differences in caries rates between sexes at Naqada, but only in the 50 + age category.

Naqadan females also had more carious lesions than both males and females at Hierankopolis. Green (2006) explained these differences in terms of both dietary and behavioral factors. Predynastic Naqadans experienced higher sugar content in their dietary staples of barley and wine compared to emmer wheat and bouza (a type of beer) consumed at Hierankopolis. Additionally, Naqadan females may have habitually chewed stalks, or rhizomes, of plants as ‘quids’, perhaps to relieve stress. This may have seemed undesirable to Naqatan males who lack dental evidence for such activity. The chewing of quids for prolonged periods may have also supplied a constant food source for oral bacteria, thus leading to the larger carious lesions observed in Naqadan females (Greene 2006).

Significantly higher female caries rates are also observed by Lukacs (1996) in his study of prehistoric hunter-gatherers and agriculturalists from the Indian subcontinent. While the disparity between the sexes was evident among hunting and foraging Mesolithic peoples, an even greater discrepancy emerged among the Bronze Age agriculturalists of Harappa. The author postulated that the most important factors were culturally mediated behavioral differences related to distinctive sex-based activity patterns, especially those connected with the preparation and consumption of food (Lukacs 1996). Sexual division of labor in procurement and allocation of resources was also the explanation given by Walker and Erlandson (1986) for the higher prevalence of caries among females observed in precontact groups from the Channel Islands of California. Ethnographic research among historic Chumash inhabitants of the same area showed that men hunted and fished, while women gathered plant foods (Blackburn

1975). If an analogous practice existed on Santa Rosa island, men may have had higher access to protein-rich animal foods than women. While the later may still have had equal access to shellfish, these are generally lower in protein, fat, and fluoride content, characteristics that would result in higher caries rate among females (Walker and Erlandson 1986).

Similar sexually dimorphic dietary trends have been observed in several groups of modern central African pygmy foragers and hunters (Aka, Mbuti, Efe) and Bantu horticulturalists. Walker and Hewlett (1990) explored behavioral interpretations for caries prevalence and their results provided some support for behaviorally mediated factors in the disparity of dental disease between sexes. For example, diets of pygmy women contained more plant material than those of men. Among the Aka, men went away for pig or elephant hunts that could last days or weeks, and ate primarily meat while they were gone. Aka women collected fruits, nuts, and tubers and helped relatives with their fishing nets in order to get some meat. However, female meat consumption among the Aka during male hunts decreased considerably because their husbands were not around to help with carrying and setting up the family nets. Increased reliance on cariogenic foods such as fruits and tubers during those times was the most likely cause for elevated caries rates among Aka females (Walker and Hewlett 1990).

Sex disparity in caries distribution has been observed in several other archaeological populations: ancient Egyptians (Hillson 1979) and Nubians (Beck and Greene 1989), prehispanic Maya (Cucina et al. 2012), the Jomon of central Japan (Turner II 1979), and Ohio Amerindians (Millner 1984). Thus culturally mediated, behavioral differences in acquisition and distribution of resources are important contributors to a sexual division in dental disease. However, there is some evidence that physiological factors may also play a role. Female teeth erupt earlier than male teeth and are thus predisposed to longer exposure to caries-promoting factors (Larsen 1997). In an early investigation in sex differences in caries rates Mansbridge (1959) addressed the relationship between dental development and caries rates in boys and girls of the same age. The author did not find support for the conclusion that earlier eruption in girls is responsible for sex differences in caries and concluded that greater caries prevalence in females was 'constitutional' in origin (Mansbridge 1959).

If by 'constitutional' Mansbridge (1959) alluded to genetic origins, modern genetic research has lent some support to his claim. In order to explore the potential genetic factors involved in caries sex differences, Vieira and coworkers (2008) evaluated genotype data and DMFT scores of 46 Filipino families with similar cultural and behavioral habits. Suggestive loci logarithmic odds (LOD) were found for both low and high caries susceptibilities. Although there were no obvious candidate genes in the five regions with the most significant results, these could range from genes contributing to enamel formation, saliva composition, or immune responses. On the low end of caries susceptibility, the authors suggested the interesting possibility that there existed a protective locus for caries on the X-chromosome. The fathers of the studied families had a lower average DMFT score than that of the mother, suggesting X-linked genetic variability for the lower caries rates observed in males. In an equally significant result, one of the two regions identified with higher caries susceptibility had a marker close to estrogen-related-receptor-beta (*ESRRB*). This gene codes for an estrogen-related protein with unknown function. Can this gene contribute to differences in caries frequency? Estrogen is known to have a depressing effect on the secretion of growth hormone from the anterior pituitary gland, which, in turn, is related to development and maintenance of normal histological structure of salivary glands (Vieira et al. 2008). The cariostatic role of saliva was briefly discussed in the caries etiology section of this work. Other researchers have reported decreased salivary flow in post-menopausal women; however, they observed no difference in salivary flow rates between women taking estrogen supplements and those who did not (Streckfus et al. 1998).

Fluctuations in estrogen levels in females as a result of life cycle events, such as pregnancy, may have a connection to the increased caries rates observed in the latter. Estrogen levels fluctuate regularly with the onset of puberty and attain maximum levels during pregnancy (Lukacs 2008). Research performed on laboratory animals provide evidence for a positive correlation of estrogen levels with caries rates, while androgens had no effect (Legler and Menaker 1980). It is plausible that higher estrogen levels in women over their life span have a cumulative and incremental effect that predisposes preadolescent girls to higher caries rates during childhood (as opposed to earlier eruption of female teeth). The fact that women's caries experience increases with age in diverse ethnic groups from different ecological and cultural settings also supports this interpretation (Lukacs 2008). Evidence from paleodemography and reproductive ecology supports the interpretation that many agricultural societies realized high fertility rates, compared to horticulturalists and foragers (Bentley et al. 2001). Decreased birth intervals and higher fertility in agricultural societies, life cycle events such as menses, puberty and pregnancy, and the resulting hormonal fluctuations, may have all worked synergistically to predispose women to poorer oral health and higher caries rates than men (Lukacs and Thompson 2008). A greater understanding of sex differences in caries prevalence may be obtained by considering these influences, and women's reproductive role in general, in conjunction with diet, behavior, and the sexual division of labor observed in most human societies (Lukacs and Largaespada 2006).

## Dental caries in Egypt and Nubia

Previous research indicates that the incidence of carious lesions remained relatively low in Egypt and Nubia overall, increasing steadily through time (Greene 2006). Ibrahim (1987) reported a prevalence of 2.2% carious teeth in the Egyptian Predynastic, 3.7% in the Dynastic, and 4.6% in later populations. In the case of Nubia, Armelagos (1966, 1969) reported that the frequencies of carious tooth lesions increased from 1% in the Mesolithic to 12.4% in the Meroitic period, decreasing to 11.8% in the X-Group period, and rising again to 18% during the Christian period. His results were somewhat corroborated by Greene (1972) who found evidence for caries on 1% of Nubian Mesolithic teeth, increasing to 15.1% in the Meroitic period.

Sir Armand Ruffer undertook the first systematic study on the oral pathology of ancient Egyptians in 1920. Ruffer (1920) mentioned that caries frequencies increased gradually from the Predynastic in Egypt to the Christian period in Nubia but presented convoluted statistical figures. For example, he examined 72 Nubian skulls and found caries on 4% of those. However it is not clear whether Ruffer (1920) was referring to 4% of the individual skulls, or of the total teeth examined. This is important since 4% of the total teeth examined in 72 skulls could amount to more than 4% of the individual specimens. The confusion was compounded later on when Ruffer mentioned that he examined 156 maxillae and 95 mandibulae of Predynastic individuals and found caries rates of 25% and 15%, respectively. Without figures for total number of carious teeth, carious teeth per tooth class, and carious individuals, it becomes difficult to determine the precise rate of carious change over time. In any case, maxillary dentitions appeared to present higher rates of dental decay than mandibular ones (Ruffer 1920).

Leek (1972a) examined 4816 Egyptian teeth with a time range from the Predynastic to the 21st Dynasty (Third Intermediate Period, 1069-945 BC), of which 39 exhibited ‘simple surface cavities’ (p. 291). This extremely low percentage runs counter to the afore-mentioned trend towards increase in caries frequencies through time. The author did not provide any other information, which precludes any appreciation of diachronic trends in caries frequencies for this study. Confusing, and conflicting at that, numbers are also presented by Grilletto (1973) in his study of Predynastic and Dynastic Egyptian skulls. The author examined 51 adult Predynastic individuals with a total of 732 teeth and 740 Dynastic individuals with a total of 9949 studied teeth. The author presented figures for both carious individuals and carious teeth for the two samples. These are 33.33% and 6.14% for the Predynastic, and 28.10% and 4.65% for the Dynastic, respectively. The apparent reduction in caries prevalence from the Predynastic to the Dynastic may be due to sampling bias, for Grilletto’s (1973) Predynastic sample was from a single site at Ghebelen and cannot be considered representative of the entire Predynastic period (5300-3000 BC). In contrast, the Dynastic sample is more temporally and spatially diverse (Grilletto 1973). Other research in the dental paleopathology of Egypt shows considerable inter- and intra-regional variation in both dietary habits and caries rates (Ibrahim 1987, Greene 2006). Thus Grilletto's (1973) results for the number of Predynastic carious individuals and teeth more likely reflect local dietary conditions in Ghebelen, than those of the Predynastic as a whole.

Hillson (1979) investigated 941 individuals ranging from the Predynastic at Badari and the A-Group in Nubia, to Christian burials, also in Nubia. For sites of the Dynastic period and later, less than 10% of the examined possessed dentitions in which 10% of their teeth were affected by dental caries. This generally low rate is in sharp contrast to the rates for calculus, which was observed among 50% of the individuals studied. Calculus is mineralized plaque, which can begin to accumulate around the gingival border. The initiation of the mineralization process is linked to the extent of plaque deposit. However, thick plaque deposits do not necessarily lead to more calculus, and other processes such as oral hygiene levels and consumption of carbohydrates also play part (Hillson 1996, Hillson 2005). The three Predynastic sites of Abydos, El-Amra, and Badari have lower frequencies of plaque-related calculus than later cemeteries. Since sugars play a major role in plaque growth (Hillson 1979), lower plaque frequencies can be associated with more limited sugar consumption in the Predynastic compared to the Dynastic periods (Hillson 1979). Finally, moderate frequencies of mild caries, mostly occlusal, were observed by Matovich (2002) on 53 individuals from the Predynastic, working class cemetery HK43 at Hierankopolis. It is possible that the HK43 individuals consumed a more abrasive and less cariogenic diet than other agricultural populations (Matovich 2002).

**Conclusion**

This chapter is an attempt to elaborate on the etiology and epidemiology of dental caries, and includes a short bibliographical review of ancient Egyptian and Nubia caries. Dental caries is an age-progressive disease process, characterized by the demineralization of the enamel surfaces of mammalian teeth. This structural break down of the tooth surface is caused by the fermentation of dietary carbohydrates by oral bacteria such as *Streptococcus mutans* and *Lactobacilii*. Caries has a multicausal etiology where diet, food preparation techniques, saliva, tooth morphology, genetic and environmental factors interact with each other in order to raise or lower pH values in the human mouth. Cariogenic bacteria such as *S. mutans* are adapted for, and thrive in, highly acidic environments where low pH values are maintained for longer periods of time. The single most important factor in the lowering of pH values in the human mouth is consumption of carbohydrates, especially sugars.  Sugars, and sucrose in particular, can be readily biodegraded by carbohydrate-processing oral bacteria. Thus regular consumption of sugary products is closely associated with increased amount of plaque bacteria, increased production of acidic byproducts, and higher rates of enamel demineralization.

In modern human populations, dental caries epidemiology is characterized by high rates of infection in subadults, and especially young children. The high rates of childhood caries are associated with frequent consumption of sugary drinks and snacks between meals, as well as socioeconomic factors such as ethnicity, level of income, level of education, and access to dental care (Thompson et al. 2004, Sheiham 2006). In archaeological populations dental caries increased in proportion to age, and older adults tend to display higher caries than young ones. Because of its association with consumption of carbohydrates, dental caries constitutes a good indicator for the transition from hunting, foraging, and gathering to an agricultural lifestyle where soft, carbohydrate-rich, agricultural products become the main dietary staples.

Procurement, preparation, and distribution of dietary sources in human societies are cultural activities characterized by sex and status divisions. Overall, in agricultural populations females and males of lower status appear to have more caries than other segments of the population (Beck and Greene 1989, Walker and Hewlett 1990, Lukacs 1992, Larsen 1997, Cucina et al. 2012). This can be the result of differential access to resources, where elite members, especially males, consume protein-rich, less cariogenic foods. For females, higher caries rates are attributed to sex divison of labor, behavioral differences in food preparation, and physiological factors such as hormonal fluctuations during life events such as adolescence and pregnancy.

Previous studies have shown that caries prevalence in Egypt and Nubia remained low but increased steadily from the Predynastic period in Egypt to the Christian era in Nubia. Such findings are in general accordance with the trend observed in other agricultural populations, where increasing reliance on soft, carbohydrate-rich, agricultural products paralleled increasing caries rates through time. A thorough discussion of Egyptian and Nubian ecology, food, and diet takes place in Chapter Two of this thesis. In general, as intense agriculture and state-level society developed in Egypt, changes in diet and food preparation techniques made soft, refined, sticky, carbohydrate-rich foods, such as bread, figs, dates, and honey, widely available to the population (Leek 1972b, Saffirio 1972, Iacumin et al. 1996, Samuel 2000). The new diet replaced the coarser diet of the earlier, Predynastic times during which people ate more meat, fish, and vegetables (Ibrahim 1987). The stickiness and high sugar content of Dynastic diet were the likely causative factors behind the increased caries rates observed during the later periods of Egyptian and Nubian histories. Caries rates frequencies in Egypt showed considerable inter-regional variation, which can be analyzed in order to assess localized dietary regimes. Based on previous research, Egyptian caries rates did not seem to differ greatly among the sexes and social classes, but differences existed on a local level. This thesis provides the opportunity to re-test these hypotheses on a larger skeletal population and over a longer period of time than attempted previously.

# CHAPTER 4

## MATERIALS

This thesis is concerned with the implications of the changes in the prevalence of dental caries over time among ancient Egyptians and Nubians. The skeletal population for this study consists of 32 samples drawn from 17 Egyptian and 15 Nubian cemeteries (Table One), encompassing1842 individuals (676 Males, 793 Females, 373 Unknown), with a total of 26196 teeth observed for caries. The skeletal material represents all four major geographical and cultural areas of Egypt and Nubia, albeit with different sample sizes. A total of 312 individuals (135 males, 142 females, 35 unsexed, hereafter refered to as M, F, and U) come from Lower Egypt, 753 (260 M, 315 F, 178 U) from Upper Egypt, 499 (188 M, 219 F, 92 U) from Lower Nubia, and 278 (93 M, 117 F, 68 U) from Upper Nubia. Age-wise, this skeletal population is divided into Children (0-10), Sub-adults (11-18), and Adults (18+). These categories number 133 (3 M, 4 F, 126 U), 157 (23 M, 71 F, 63 U), and 1544 (650 M, 718 F, 176 U), respectively. Sex information was used in this thesis as it appeared in the original field report for the various samples. For the purpose of social status comparisons, the skeletal population has also been grouped into Lower, Middle, and Upper class components. These number 312 (69 M, 122 F, 121 U), 134 (48 M, 66 F, 20 U), and 491 (223 M, 201 F, 67 U), respectively, for a total population of 905 individuals (49.13% of total sample). Once again this information was used as it appeared in the field report forms and is graphically represented in Table 3. The various samples that provided caries data for this study were excavated by a number of researchers and archaeologists over a period of more than a century.

**Table 3.** Sex, age, and social status of the skeletal population

| | Country | | Region | | | |
|---|---|---|---|---|---|---|
| | Egypt | Nubia | Lower Egypt | Upper Egypt | Lower Nubia | Upper Nubia |
| **Males** | 395 | 281 | 135 | 260 | 188 | 93 |
| **Females** | 457 | 336 | 142 | 315 | 219 | 117 |
| **Unsexed** | 213 | 160 | 35 | 178 | 92 | 68 |
| **Total** | 1067 | 777 | 312 | 753 | 499 | 278 |
| | | | | | | |
| **Children** | 59 | 74 | 14 | 45 | 51 | 23 |
| **Sub-adults** | 97 | 60 | 29 | 68 | 41 | 19 |
| **Adults** | 903 | 641 | 269 | 634 | 405 | 236 |
| **Total** | 1059 | 775 | 312 | 747 | 497 | 278 |
| | | | | | | |
| **Lower status** | 313 | | | 313 | | |
| **Middle status** | 134 | | 62 | 72 | | |
| **Upper status** | 399 | 32 | 172 | 227 | | 32 |
| **Total** | 846 | 32 | 234 | 612 | | 32 |

The first sample in this study to be unearthed was from the New Kingdom cemetery at Qurneh (QUR, see Table Four for cemetery abbreviations) in Lower Egypt, which was excavated by E.W. Budge in 1887 (Irish 2006). Other notable early excavators of these skeletal samples included Sir Flinders Petrie (BAD, NAQ, ABD, TAR, GIZ, HAW), Felix von Luschan (THE, HES), and George Andrew Reisner (KER). From 1970 onwards, the building of the Aswan Dam led to extensive and ongoing salvage excavations in both Egypt and Sudan which were undertaken by a number of American, Canadian, Scandinavian, Polish, French, Italian, Egyptian, Sudanese, British, Belgian, and Dutch archaeologists. The remaining samples in this study originated in one or more of these combined archaeological efforts (Wendorf and Schild 2001, Kobusiewicz et al.

2004, Irish 2005, 2006, Schillaci et al. 2009, Irish and Friedman 2010). The sex, age, and status information provided in Table Three was reproduced by the field researcher who collected the dental caries data, Dr. Joel D. Irish, and in accordance with the records kept at the various museums and laboratories where the samples are presently curated. These

**Table 4.** Sample abbreviation and curation.

| Region | Cemetery | Abbreviation | Curation |
|---|---|---|---|
| Upper Egypt | Badari | BAD | CAM |
| | Naqada | NAQ | CAM |
| | OK Hill | OKH | On site |
| | Hierankopolis | HRK | On site |
| | Abydos Predynastic | ABP | Abydos German House |
| | Abydos Dynastic | ABD | BMNH |
| | Thebes | THE | AMNH |
| | HK27C | HCG | On site |
| | Qurneh | QUR | CAM |
| | El-Hesa | HES | AMNH |
| | Kharga | KHA | BMNH |
| Lower Egypt | Tarkhan | TAR | CAM |
| | Saqqara | SAQ | MH |
| | Lisht | LIS | NMNH |
| | Giza | GIZ | CAM |
| | Saqqara/Manfalut | GEG | MH |
| | Hawara | HAW | BMNH |
| Upper Nubia | Al-Khiday Mesolithic | AKH | DUR |
| | Al-Khiday Neolithic | AKM | DUR |
| | R12 | R12 | PITT |
| | Kerma | KER | CAM |
| | Kawa | KAW | BM |
| | Soleb | SOL | MH |
| | Kushite | KUS | BM |
| Lower Nubia | Jebel Sahaba | JSA | AMNH |
| | Gebel Ramlah | GRM | On site |
| | A-Group | AGR | PAN |
| | C-Group | CGR | PAN |
| | Pharaonic | PHR | PAN |
| | Meroitic | MER | ASU, PAN |
| | X-Group | XGR | ASU, PAN |
| | Christian | CHR | ASU, PAN |

locations are presented on Table 4. The key for the abbreviations on the table is as follows: CAM = Duckworth Laboratory, Cambridge University; BMNH = British Museum of Natural History; AMNH = American Museum of natural History; MH = Musèe de l'Homme; DUR = Durham University; PIT = University of Pittsburgh; ASU = Arizona State University; PAN = Panum Institute, University of Copenhagen (Irish 2005). Social status information was available for individuals recvered from 14 cemeteries, mainly Egyptian, and was assigned by the original excavators of the samples and based on burial goods associated with the interred. A more detailed discussion of the sex, age, and status composition of the population, as well as issues relating to statistical representation of skeletal samples, takes place in Chapter Five. Additional information on individual samples, whenever the latter was available, is offered later in this section.

As can be observed from Table One, the temporal span of the skeletal population is considerable and extends from Late Paleolithic Nubians (14000-12000 BCE) to medieval Christians, again in Nubia (1350 CE). Although many of these samples have been included in previous craniodental analyses of regional and wider African population affinities (Martin et al. 1984, Johnson and Lovell 1994 and 1995, Irish 1998a 1998b, 2000, 2005, 2006, and 2008, Irish and Hemphill 2004, Schillaci et al. 2009, Irish and Friedman 2010), no study has approached such temporally extensive material from the point of dental caries. The following section provides synoptic information about the various cemeteries including sample size, sex composition, location, and cultural background whenever this is available. Three-letter abbreviations for the cemeteries will be used extensively in the remaining of the thesis. These abbreviations are used to designate the various cemeteries in SPSS, and are also mentioned in Figure 1 below.


**Figure 1.** Location of most cemeteries. AKH and AKM are located near the river confluence at the bottom; SOL lies between AGR and KER; OKH is near HRK; and JSA is near XGR (replicated with permission from Irish and Friedman 2010).

## Preagricultural/Prehistoric cemeteries

*Jebel Sahaba* (JSA n = 57)

Jebel Sahaba is a prominent sandstone inselberg located on the eastern bank of the Nile, three km north of Wadi Halfa in northern Lower Nubia (Wendorf 1968). The JSA sample derives from three Late Paleolithic cemeteries (SMU 67/5A, 80, and 117) excavated by Fred Wendorf and associates from Southern Methodist University in 1968. The Late Paleolithic Sahabans recovered at the sites were buried in simple, shallow, oval graves, where both single and multiple internments occured. They represent pre-agricultural nomads with lithic affinities to the Qadan industry (13000-4500 BCE) in Lower Nubia (Wendorf 1968, Irish 2005). Based on archaeological evidence from other Qadan sites along the Nile, Late Paleolithic Egyptians practiced a mixed lifestyle of seasonal and specialized activities organized around fishing and the hunting of large game (Clark 1971, 1980, Hassan 1980). Faunal remains from these sites were dominated by wild cattle, red-fronted gazelle, hartebeest, hippo, auruch, several species of catfish, rabbit, bird, and shell-fish (*Unio sp.*) (Clark 1980, Hassan 1980, Ibrahim 1987). As was mentioned in more detail in Chapter Two, Qadan sites also produced numerous grinding stones with the characteristic ‘sickle sheen’ caused by the grinding of soft, fibrous material. Chemical analysis (using pyrolysis mass spectrometry) of a mortar-cum-grinder revealed that the working surfaces had been used to grind starchy vegetables, such as the tubers of nut-grass (*Cyperus rotundus*) and club-rush. The latter are abundant through the

Nile Valley even today and must have also occupied the seasonally inundated marshes and meadows of the Nile Valley in great numbers during the Paleolithic. Other plant foods included fragments of the dot-palm fruit (*Hyphaene thebaica*), an extinct water lily, and seeds belonging to three species of the chamomile tribe (*Anthemidae*) (Wetterstrom 1993a).

JSA is significant because of its antiquity. Based on lithic typology and comparisons with other Wadi Halfa locations, the individuals of the combined JSA sample have been tentatively dated 14000-12000 BCE (Wendorf 1968, Irish 2005). This represents the oldest skeletal series from a period in Nubia that offers little or no human osteological material to-date. Additionally, almost half of the individuals from JSA Site 117 have been found in association with microlithic material that is directly responsible for the individual's death. Various types of blades, flakes, and chips were found embedded in the skeleton of 24 individuals recovered at the site (Wendorf 1968, Bard 2008). This unambiguous evidence of human-mediated violence and death has been explained in terms of increased resource competition between various groups, in the context of worsening environmental conditions and increased aridity during the Terminal Paleolithic (Wendorf 1968, Wendorf 1980a).

*Al Khiday* (AKH n = 40, AKM n = 25)

Al Khiday is located in the El Salha area, south of Khartum's suburb of Omdurman in central Sudan. Since the year 2000, the area has been undergoing extensive fieldwork under the direction of the Italian Institute for Africa and the Orient (Is.I.A.O).

The Al Khiday sub-sample in this study comes from the mixed Late Paleolithic, Mesolithic, and post-Meroitic cemetery of Al Khiday 2 (16-D-4), first excavated in 2004 (Usai and Salvatori 2008). The 25 individuals of the Mesolithic component (AKM) in this study derive from the total of 45 such burials excavated at the site. From these, 37 were found in an unusual elongated position unknown in other parts of the world. This type of burial was encountered only once at a Wadi Kubbaniya site in Egypt, and is absent from elsewhere along the Nile (Usai and Salvatori 2008). Dating of the burials remains inconclusive but the unusual burial position, the fossilized state of the bones, and the superposition of some of the burials with younger, Mesolithic ashy pits place the elongated ventral burials at the Late Paleolithic/Early Mesolithic period, at least > 9000 BCE (Usai and Salvatori 2008). The remaining 40 individuals comprise the Late Mesolithic component (AKH) of the Al Khiday sample in this study. They have been dated to 6650-6460 BCE, based on two shells found in the ashy pits associated with these later burials (Usai and Salvatori 2008).

Isotopic analysis of carbon, nitrogen, and oxygen from collagen and apatite showed that important dietary changes took place from the Paleolithic to the Mesolithic at Al Khiday. The Late Paleolithic group with the unique burial position ingested C4 plants, including sorghum, and lived in a more humid environment. In the contrast, the Late Mesolithic group had a diet higher in C3 plants and lived in environmental conditions more similar to modern ones, i.e. hotter and dryer (Usai and Salvatori 2008).

*R 12* (R12 n = 50)

R12 is located in the Dongola region of Upper Nubia. The cemetery was discovered and excavated between 2000 and 2003 by a joint effort of the *Centro Veneto di Studi Classici e Orientali* and the Sudan Archaeological Research Society (SARS) (Salvatori and Usai 2008). Over the span of three excavation seasons, 166 graves yielded a total of about 200 individuals accompanied by a rich cultural component. The latter included handmade pottery bowls and jars, bone spatulas fashioned from ovicaprine or gazelle tibiae, perforators made from mammalian bones, and personal items such as stone and ivory bangles, semi-precious necklaces and bracelets, and ivory or stone pendants (Salvatori and Usai 2002, 2008). Some of the most impressive ceramic artifacts at R12 involved elegantly made caliciform, or ‘tulip’, beakers decorated with impressed geometric or banded designs on the whole external and inner surface of the flaring rim. Charcoal samples from the site have provided dates between 4810-4720 BCE. The burial practices and ceramic style at R12 are similar to the neighboring and contemporaneous cemetery of Kadruka and fall within the overall Khartoum Neolithic tradition observed in Upper Nubia and central Sudan at this time (Salvatori and Usai 2001, 2002).

From a dental anthropological perspective, the individuals from R12 displayed robust mandibles with severe macroscopic wear on the teeth. Wear was such that many teeth had become unsuitable as age indicators (Crivellaro 2001). Anterior teeth from R12 showed heavy angled wear while molars and premolars had the cup-shaped wear that is characteristic of abrasive diets composed of foodstuffs with reduced toughness and fibrousness  (Smith 1984b, Crivellaro 2001). Extra-masticatory behaviors, perhaps associated with manipulation of animal skin or tendon, were indicated by the presence of lingual surface attrition of the maxillary anterior teeth (LSAMAT) on the central upper incisors of two adult male individuals from the site (Crivellaro 2001). Dental disease is of generally low prevalence at R12 with males and females showing a mean for carious teeth of 0.24 and 0.20, respectively. This is well below the mean for populations associated with agriculture, i.e. the ones that display similar wear patterns to R12. The low caries prevalence suggests that the wear patterns of the anterior and posterior teeth observed at R12, were caused by consumption of abrasive, semi-processed wild plants and meat, rather than agriculturally-produced cereals (Judd 2008). Meat consumption is also supported by the site's faunal record, which included domesticated as well as wild cattle and caprines, hippopotami, and elephants (Iacumin 2008).

*Gebel Ramlah* (GRM n = 59)

Gebel Ramlah (Sandy Mountain) is an isolated part of the Kiseiba scarp located in the southwestern desert of Egypt (Lower Nubia), some 250 km southwest of Aswan. The area has been undergoing systematic field surveys by the Combined Prehistoric Expedition since the 1970s (Wendorf and Schild 2001, Kobusiewicz et al. 2004, Irish 2008). During the 2000 and 2001 field seasons, field investigators discovered a cluster of Neolithic sites at the foot of the mount, and near the shore of an ancient, internally drained playa (Schild et al. 2005, Kobusiewicz et al. 2004). Initial excavations showed that GRM was a complex site with multiple levels of occupation. In one location, excavators unearthed geomorphic evidence for a round, shallow basin house and a stonewalled fireplace measuring 3 m (9.84 ft) in diameter. Elaborate construction of the fireplace suggested that it was high temperature and provided a large burning area for its users. Charcoal samples from this location have yielded a radiocarbon date of 5032-4868 BCE (Schild et al. 2005). Other radiocarbon analyses have indicated more recent dates between 4666-4532 BCE and 4454-4360 BCE (Irish 2008).

While some of the skeletons at the site were discovered after having been exposed to the wind, and were extremely deflated, most were deposited in pits 60-80 mm below the surface (Kobusiewicz et al. 2004). Osteological evaluation by the team's physical anthropologist (Dr. Joel D. Irish) showed that the GRM individuals possessed good overall health with no trauma, low incidence of skeletal pathologies, and minor wear on teeth. The oblique, occlusal angle observed on teeth of some older individuals indicates consumption of highly processed foodstuffs (Kobusiewicz et al. 2004, Schild et al. 2005).

Pottery from GRM included 'tulip' beakers similar to those from R12, 'rippled' wares, and black top variants. All of these are similar to pottery types from the subsequent Badarian culture in Upper Egypt. The tulip beakers, together with other elements of material culture such as palette kits, ivory bracelets, and flint artifacts have parallels in other Late Neolithic Nubian, central Sudanese, and eastern Saharan sites. Further, the 'rippled' surface and 'black-topped' wares that have been identified with the Badarian culture in Egypt are also diagnostic of the terminal Abkan pottery in Lower Nubia; the latter was the forerunner of the 'rippled' wares, also characteristic of the Nubian A-Group (Hays 1984). These findings suggested that at least some elements of the Badarian culture may have originated in the southwestern Egyptian desert (Hassan 1997a, Kobusiewicz et al. 2004, Peressinotto et al. 2004).

## Predynastic cemeteries

*Badari* (BAD n = 40)

The geographic core of the Badarian culture was centered on the region of el-Badar, near the modern town of Sohag, and may have reached as far south as Hierankopolis (Hendrickx and Vermeesch 2000). This core area of Mostagedda-Matmar-Badari-Hammamiya has produced the earliest evidence of farming communities (Wetterstrom 1993a) and ceramic-bearing sites in Upper Egypt, ca. 4032-3600 BCE (Hays 1984). Badarian populations subsisted primarily on simple, basin irrigation agriculture of emmer wheat and barley, supplemented by animal husbandry of both wild and domesticated cattle, sheep, and goats (Hassan 1988, Greene 2006, Bard 2008). Ancient Badarians also relied at least partially on hunting as suggested by the faunal remains of species such as gazelle, hippo, turtle, and crocodile that have been found in association with Badarian sites. Lesser cultigens included flax, lentils, tubers, and velch, which was most likely used as animal fodder (Wetterstrom 1993a, Greene 2006). The discovery of ladles and spoons at Badarian sites suggested that lentils may have been prepared into some kind of gruel or leguminous soup (Saffirio 1972). Fishing seemingly played a diminished dietary role relative to previous Neolithic cultures, and only a few species of catfish were recovered at Badarian sites (Wetterstrom 1993a). Additionally, Badarians showed signs of increased social differentiation and were most likely organized into village chiefdoms where local elites, or chiefs, retained control of trade in luxury mortuary goods (Hassan 1997b).

The 40 individuals (19 M, 18 F, 3 U) from Badari that are part of this study represent incipient Predynastic farmers and were recovered by Petrie for a British School of Archaeology expedition. The skeletal remains are presently curated at Cambridge University (Irish 2006).

*Naqada* (NAQ n = 65)

Naqada is located on the west bank of the Nile, about 28 km (17.4 m) northwest of modern Luxor (Bard 1989). The area was extensively excavated by Petrie and Quibell who, collectively, uncovered over 15000 graves for the whole Predynastic period (Midant-Reynes 2000). The Naqada cemeteries thus represent the largest Predynastic burial sites in Egypt, and an important location for the study of early state evolution/formation and cultural change (Bard 1989). From a dietary perspective the Naqada culture is characterized by an increase in the importance of farming and a parallel decrease in hunting and fishing activities compared to the previous Badarian culture. Plant remains from Naqadan sites included figs, peas, jujubes, a kind of watermelon, wild dot palm, as well as several species of Nilotic tubers and roots, none of which was previously encountered in a Badarian context (Wetterstrom 1993a, Greene 2006). Husbandry of domesticated animals was augmented with the addition of the pig, while literary and pictorial evidence testifies that by Naqada III ancient Egyptians had adopted complex canal irrigation characterized by sluice and flood-gate systems (Wetterstrom

1993a). Hunting continued to provide some animal protein to the Naqadan diet, but it seems that emphasis had now shifted to the taking of smaller animals such as hare, turtle, monitor lizard, wild cat, hyena, and several species of birds (Van Neer and Linseele 2002).

The 65 individuals (17 M, 34 F, 14 U) that provided the caries data for this study came from three cemeteries in Naqada's South Town (Cemeteries B, T, and the "Great Race"). According to Petrie, these individuals were dated to Naqada I and II periods (4000-3200 BCE). Based on attribution of burial wealth they are believed to be of mixed social status, mostly lower (Johnson and Lovell 1994, Irish 2006).

*Abydos* (ABP n = 62)

These 62 (26 M, 36 F) individuals are also associated with Naqada I (Amratian, 4000-3500 BCE) and II (Gerzean, 3500-3200 BCE) periods (Irish and Friedman 2010). Compared to Naqada I, Naqada II is characterized by increased social complexity and geographic expansion (based on artifacts) northwards into the Delta and southwards into Nubia. During Naqada II fundamental changes take place in funerary ritual including possible evidence for self-sacrifice, or ritualistic human sacrifice and burial. This can be considered a prelude to the mass human sacrifices that accompany the early Dynastic kings buried at Abydos (Midant-Reynes 2000). Based on burial goods the ABP sample is associated with upper status individuals. If the burial customs of the time included ritualistic sacrifice, some of these individuals may have been forcibly or voluntarily sacrificed after the death of the ruler.

*Hierankopolis* (HRK n = 248)

The HRK sample (51 M, 88 F, 109 U) was excavated by members of the Hierankopolis Expedition. Based on burial goods, the sample is composed of lower-class individuals associated with a Naqada II archaeological horizon (Irish 2006, Irish and Friedman 2010). During late Naqada I-Naqada II, the Hierankopolis region experienced a population explosion and may have reached a population of 5000-10000 in the central area alone (Hoffman et al. 1986). Increased craft specialization was centered upon pottery manufacture as the major growth industry. Other crafts included stone working (maces, groundstone vases, pigment palettes), basketry, linen manufacturing, and the hammering of copper into axes, blades, bracelets, and rings. Social stratification intensified, with workers having various amounts of prestige based upon their craft (Hoffman et al. 1986, Midant-Reynes 2000, Greene 2006). Skeletons from the working class cemetery HK43 bore evidence of decapitation and/or defleshing, most likely associated with ritualistic or punitive action (Dougherty and Friedman 2005). These social changes may have been spurred by environmental conditions of increased aridity and desertification that promoted floodplain agriculture and exploitation of domesticated animals as the main subsistence strategies. This combination of cultural and environmental factors is largely responsible for the transformation of Hierankopolis into the capital of a large, southern Egyptian state during this time (Hoffman et al. 1986).

## Dynastic cemeteries

*Dynastic diet and subsistence*

The Dynastic period began around 3000 BCE and lasted until the conquest of Egypt by the armies of Alexander the Great in 332 BCE. During this remarkably long period, Egyptian diet continued to depend on the agricultural staples of emmer wheat and barley. Linguistic (textual) evidence suggests that barley was the dominant crop during the Old and Middle Kingdoms, whereas from New Kingdom until the Ptolemaic period wheat became the more important of the two (Murray 2000). The reasons for this shift are not clear but some role may have been played by the improvements in irrigation during the New Kingdom, especially the introduction of the pole-and-bucket lever, or *shaduf* (Butzer 1976). Barley is tolerant of a wide range of environmental conditions, its geographical range is checked only by extreme cold, and can withstand heat and aridity much better than wheat (Flannery 1973). In relation to the latter, textual evidence also indicated that barley was the major crop in Upper Egypt whereas emmer wheat was grown primarily in Lower Egypt (Kemp 1994). This is not accidental if one considers that the latter is cooler, receives more rainfall per annum, and is better irrigated (because of the Delta) than its southern counterpart.

In any case, both barley and wheat were used in the manufacturing of the two Dynastic staples, bread and beer. Egyptian bread was leavened, made into various shapes, some of which had religious significance, and was sometimes was filled with fruits or dates (Morcos and Morcos 1977). Ancient Egyptian beer was used as daily foodstuff and was probably less alcoholic than its modern equivalent. It was rich in vitamins and protein, and was safer to drink than river, canal, pond, or well water. It was thus made widely available in ancient Egyptian society and was used, as was bread, as means of payment for soldiers, diplomats, and other state workers (Geller 1992).

Bread and beer were part of all three of the daily Egyptian meals and were supplemented with animal protein from beef, fowl, and fish, vegetables (papyrus rhizome, lotus, onions, turnips, tubers, chickpeas, beans, garlic, leek, lentils), fruits (oil palms, melons, figs, dates, cucumbers, grapes), eggs, milk, and cheese (Morcos and Morcos 1977). Isotopic analyses of animal and human bone provide evidence that the human diet did not change much during the Dynastic period and consisted mainly of consumption of C3 plants, and/or domestic animals (sheep, pig, goat, with lesser degree of cattle consumption) that consumed C3 plants (Iacumin et al. 1998, Thompson et al. 2005). Additionaly, ancient Egyptians also made wide use of masticatories, or chewing quids. The latter were provided by the lower end of the papyrous plants, most likely for its sweetness, or perhaps as means of deodorizing the breath and mouth. In regards to the last, Egyptians also chewed natron, a naturally occurring compound of sodium carbonate and sodium bicarbonate. Today natron is mixed and chewed with tobacco in order to freshen the mouth; it is thus likely that chewing of natron served a similar purpose in antiquity (Dixon 1972).

*Abydos* (ABD n = 54)

In the early Dynastic Egyptian state Abydos became the most important center of the mortuary cult associated with divine kingship and its ideology. As an attestation to the latter fact, all of the First and Second Dynasty kings are buried at the Royal Cemetery at Abydos (Bard 2000). The 54 individuals from ABD (36 M, 13 F, 5 U) were excavated by Petrie in 1899-1901 from subsidiary burials surrounding the royal tombs; they are presently under curation at the British Museum of Natural History. The skeletal remains represent palace officials and other elite members, presumably sacrificed and buried upon the death of the king (Bard 2000, Irish 2006).

*Saqqara* (SAQ n = 41)

During the Early Dynastic period, Saqqara became the burial place for the palace officials and other important members of the bureaucratic and religious elite that served the king at Abydos. Saqqara is located roughly 30 km (18.6 m) south of modern-day Cairo and at a distance of approximately 498 km (309.5 m) north of the Early Dynastic capital. The choice for an elite burial place so far removed from the seat of royal government likely incorporated a symbolic message, perhaps pertaining to the ideo-belief system of the Early Dynastic state. The cemetery is located on a prominent limestone ridge overlooking the river valley and it is composed of elaborate, niched superstructures over subterranean tombs in emulation of the royal tombs at Abydos. The presence of such important state monuments near the Delta was symbolic of the centralized and effective rule of the king all across the realm, from north to south (Bard 2000). The 20 males, 13 females, and 8 individuals f unknown sex that compose the SAQ sample in this study belong to royal or wealthy elite from Old Kingdom's Fourth Dynasty, ca. 2613-2494 BC, and are presently curated at Musée de l'Homme in Paris, France (Irish 2006).

*Tarkhan* (TAR n = 51)

Tarkhan is located about 50 km (31 m) south of modern-day Cairo on the western bank of the Nile and not far from Saqqara. Excavated by Petrie, Tarkhan dates mostly to Early Dynastic and Old Kingdom periods, with only a few graves belonging to Middle and New Kingdom (Grajetzki 2008). Archaeological finds from earlier burials include impressive mastaba tombs with shaft, chamber, and facade superstructures similar to those at neighboring Saqqara. With over 2000 tombs, Tarkhan is one of the most important cemeteries around the time of state formation in Egypt (www.digitalegypt.ucl). The Tarkhan sample in this study (24 M, 24 F, 3 U) represents Early Dynastic palace officials and it is presently kept at Cambridge University (Irish 2006).

*OK Hill* (OKH n = 19)

Old Kingdom Hill refers to a cluster of Dynastic rock-cut tombs excavated by members of the Hierankopolis Expedition, in association with the British Museum and the American Research Center in Egypt. The tombs were located on a hilly sandstone outcrop (inselberg) northwest of the predynastic town at Hierankopolis, and ranged in antiquity from early Old Kingdom to very late New Kingdom periods (www.hierankopolis-online.org). Although Hierankopolis declined in importance during the Dynastic period, the area retained some of its earlier religious significance (see Chapter Two) and members of the elite continued to be buried there. OKH has provided some of the best-preserved examples of provincial funerary wall paintings anywhere in Egypt, especially those in the tomb of Horemkahawef, supervisor of priests and overseer of fields under the Theban rulers of the 17th Dynasty (1580-1550 BCE) (www.hierankopolis-online.org). The OKH sample in this study is composed of upper class individuals from the same historical period, i.e. Second Intermediate (1650-1550 BCE), and consists of four males, one female, and 14 individuals of unknown sex (Irish 2013, personal communication). Existing research suggests that the diet consumed by individuals of similar social status to Horemkahawef differed from that of the commoners of their time and may have included, among other things, higher consumption of cattle, honey, and wine (Morcos and Morcos 1977).

*Thebes* (THE n = 54)

Thebes (Waset in ancient Egyptian) is located 800 km (497 m) south of the Mediterranean coast, at the foot of Nile's Qena Bend in Upper Egypt, and within the city limits of modern-day Luxor. Although the area was inhabited since Predynastic times, Thebes becomes historically noticeable during the First Intermediate Period as the capital of the Upper Egyptian state. It was from there that the kings of the 11th Dynasty set forth to reunify Egypt under one ruler (Bard 2008). After unification Thebes became the capital of Egypt and the region witnessed considerable building activity, mainly under the 11th Dynasty rulers. Mentuhotep II (2055-1985 BC) began the building of a temple dedicated to god Montu at Tod, 20 km (12.4 m) south of Luxor. A treasure discovered under the floor of the temple yielded rich artifacts in gold, silver, and lapis lazuli as well as imported goods from the Aegean and Mesopotamia (Bard 2008). At the beginning of the 12th Dynasty the Egyptian capital was moved from Thebes north to Itjtawy and the former temporarily ceased to be the burial place for kings. The area, however, remained an important cult center of the god Amun and the burial place for members of the elite. The THE sample in this study (16 M, 34 F, 4 U) represents upper class individuals from the 11th and 12th Dynasties, it was assembled in 1904 as part of the Felix von Luschan Collection, and it is presently under curation at the American Museum of Natural History (Irish 2006).

*Lisht* (LIS n = 61)

Lisht became the burial place for the founder kings of the 12th Dynasty and is distinguished by the pyramids and mortuary complexes of Amenemhat I (1985-1956 BC) and his son Senusret I (1956-1911 BC). It was located east of the northern Fayum, presumably close to the yet-to-be-located 12th Dynasty capital at Itjtawy (Bard 2008). The sample in this study consists of 23 M, 32 F, and 6 U. Based on association with burial goods, and the records at the National Museum of Natural History where the collection is kept, the latter is thought to represent upper class individuals, perhaps members of the administrative elite of the time. Quantitative analyses of craniodental data from a number of diachronic Egyptian groups show the LIS sample is biologically divergent from all others. This difference may be explained as a result of: a) endogamic practices among members of an elite group; b) increased levels of in-migration from Upper Egypt; or c) substantial extra-regional migration and gene flow during the Middle Kingdom and/or Second Intermediate Period (Irish 2006, Schillaci et al. 2009).

*Qurneh* (QUR n = 67)

QUR constitutes the sole New Kingdom cemetery for this study. It is located on the west bank of the Nile, across from modern-day Luxor and near the New Kingdom capital, Thebes. EW Budge excavated QUR in 1887 and the collection is currently curated at Cambridge University. Museum records show that burial goods associated with most specimens indicate upper class individuals from the time of Rameses II, ca. 1294-1279 BCE (Irish 2006).

### Late Dynastic and Greco-Roman cemeteries

Important technological and agricultural innovations took place during the Ptolemaic and Roman periods of Egyptian history. Under the Ptolemies, extensive land reclamation work, especially in the Delta, as well as the introduction of the animal-drawn water wheel (*saqqia*), served to triple the cultivable land available and increased agricultural output (Butzer 1976). The same period witnessed the gradual replacement of Egypt's traditional staple (by that time), husked emmer wheat, with a naked variety, *Triticum durum.* The latter is a free-threshing grass, i.e. it is easier to separate the grain from the chaff during threshing, and thus required less labor expenditure for processing (Murray 2000). The introduction of domesticated sorghum as a third crop (besides wheat and barley) harvested in summer also ensured that now agriculture became a year-round operation in Egypt. Incorporation of Egypt into the Roman Empire ca. 30 BCE propelled the country to the forefront of the Empire's worldwide trade with India, Arabia, Malaysia, and possibly even China (Peacock 2000). As a result, sugar and the sugar cane were introduced into Egypt sometime during the first century AD (Dixon 1972). Both the Ptolemies and the Romans also made widespread use of a native Egyptian sweetener, honey. Previous to the Greco-Macedonian takeover of Egypt, honey was reserved for kings and as offering to the gods. After that honey became incorporated into everyday diet, and could be combined with bread to produce a sweeter (and stickier) product aimed at consumers with a 'sweet tooth' (Pain 2005). Overall, it can be said that Greco-Roman agricultural and dietary habits impacted Egyptian diet with an increase in consumption of carbohydrates, and especially sucrose. These developments lead to a net increase in caries, and researchers have reported individual caries as high as 34% during this period (Pain 2005).

*Giza* (GIZ n = 62)

The individuals from GIZ (24 M, 25 F, 13 U) were excavated by Petrie in 1906-07. Very little else is known about them, other than they belonged to Late Dynastic horizons (Irish 2006). Chronologically this coincides with the Saitic and Persian periods of Egyptian history, ca. 664-332 BCE.

*Greco-Egyptian* (GEG n = 46)

This particular sample (21 M, 22 F, 3U) is included in this study in order to represent the Ptolemaic period of Egyptian history (332-30 BCE), during which Egypt was ruled by the descendants of Ptolemy I, one of Alexander the Great's generals in his wars with the Persian Empire (Bard 2008). Socially, Ptolemaic Egypt consisted of a wary coexistence between a Greco-Macedonian urban administrative elite and an overwhelmingly Egyptian rural population. Although Greeks remained the overall minority, some Greek influx must be expected upon Egypt at this time with the settlement of army veterans and specialists in areas of economic interest, and especially in the Fayum and the Delta (Lloyd 2000). In order to better represent the mixed society of the Ptolemaic period, GEG is heterogeneously composed of individuals from a Ptolemaic cemetery at Saqqara and a Middle Egyptian cemetery at Manfalut (Irish 2006). Quantitative analyses of non-metric dental traits that compared GEG to other diachronic Egyptian samples showed that GEG was significantly different than all others. If one discounts the possibility of statistical bias, these results suggested eithersome degree of foreign admixture in the areas represented by GEG or that the sample consists of actual Greeks. The latter possibility can be verified with future comparisons of GEG to other Greek specimens (Irish 2006).

*Hawara* (HAW n = 51)

Hawara is located in the Fayum area of Lower Egypt, south of the ancient Crocodilopolis (Arsinoe). The site was excavated by Petrie in 1890 and it is mostly known for the impressive mortuary complex and pyramid of the 12$^{th}$ Dynasty king Amenemhat III. North of the Middle Kingdom cemetery, Petrie excavated an early Roman period cemetery (50-120 CE) that, among other finds, has yielded the famous ‘mummy portraits’. These realistic and vibrant paintings depicted the deceased in the prime of their lives and were set into the head of the mummy case (Peacock 2000). The

HAW sample in this study (23 M, 26 F, 2 U) was derived from this latter site and is composed of upper class individuals from the Fayum population at the time (Irish 2006).

*El Hesa* (HES n = 72)

El Hesa was an island on the Nile near Aswan that has now been submerged after the construction of the Aswan Dam. El Hesa lies just south of the island of Elephantine and during the Roman period the area witnessed considerable building activity in association with the garrisoning of the First Legion (Maximiana) in a nearby fort (Poole 1999). The skeletal sample in this study was composed of 26 M, 41 F, and 5 U individuals, derived from a late Roman (200-400 CE) middle class cemetery excavated in 1907-08 for the von Luschan collection (Irish 2006).

Direct dietary information was not available for the inhabitants of the cemetery. However, a stable isotope analysis of human mummies from the partially contemporaneous Greco-Roman site of Kellis in the Daklaha Oasis (200 BCE-300 CE) indicated that the inhabitants there consumed an almost exclusively C3 plant diet, such as wheat, barley, and fruits. Elevated $\delta^{15}N$ values in the same sample suggested that the latter were due to consumption of C3-eating sources of meat protein, such as chickens and/or their eggs (Aufderheide et al. 2003). It is thus likely that HES individuals had a diet similar to that discussed elsewhere in this section for the Greco-Roman period in Egypt.

*Kharga* (KHA n = 26)

This sample (16 M, 10 F, 6 U) came from two Byzantine era (500-600 CE) cemeteries at El-Bagawat and Ain et-Turba, located in the Kharga Oasis of the Egyptian western desert (Irish 2006). No information exists on social status of the interred, but based on the simplicity of the graves and funerary objects they are thought to represent lower class farmers (Irish 2006). Stable carbon and nitrogen isotope analysis of skin and hair from mummified individuals indicates that the residents of Kharga Oasis during this time consumed year-round a diet dominated by C3 plants with a very minor C4 component (White et al. 1999). When compared to other Egyptian populations, the individuals from Kharga show very similar $\delta^{13}C$ values with Predynastic and Dynastic skeletons from Gebelein and Asyut (White et al. 1999). It is thus assumed that they too subsisted mainly on emmer wheat and barley. Cultivation of C3 plants requires more water than arid-adapted C4 crops, and Kharga's ability to sustain the latter should come as no surprise considering that the area continues to be fed by considerable underground springs even to this day. In antiquity Kharga was well known for its ability to produce wine (another C4 plant) and the area was a major provider of the latter to the Egyptian court during the Second Intermediate period (White et al. 1999)

## Nubian cemeteries

The preagricultural/prehistoric component of this study is entirely composed of Nubian samples and information about them is provided at the beginning of this chapter. Of the five preagricultural/prehistoric cemeteries, three are located in Upper Nubia

(AKH, AKM, R12) and two are located in Lower Nubia (JSA, GRM). For the comparative purposes of this study, the rest of Nubian cemeteries have been grouped into Early Nubian (AGR, CGR, HCG), Classic Nubian (PHA, KER, KAW, KUS), and Late Nubian (MER, XGR, CHR). Diet during these periods is believed to have been highly variabe in Nubia and it will be examined individually, granted that such information is available for the samples in question.

### Early Nubian cemeteries (3400-1450 BCE)

*A-Group* (AGR n = 52)

A-Group populations (3400-2400 BCE) were incipient agriculturalists who practiced a mixed economy of domesticated grain (millet) agriculture combined with the herding of domesticated goats and cattle (Beckett and Lovell 1994). Archaeological evidence for a greater reliance of A-Group populations on cultigens compared to previous Neolithic cultures is provided by the numerous storage pits, grinding stones, and chert blades used for harvesting that have been found in A-Group sites (Bard 2008). However, previous investigations of dental caries rates in the A-Group samples were low (2.7%) and hunted animals, fish, and seeds of wild plants also provided a considerable component of the diet (Martin et al. 1984, Beckett and Lovell 1994). The A-Group sample in this study was recovered by the Joint Scandinavian Expedition between Egypt's Faras to the north and Gamai in Sudanese Nubia. It consists of 18 males, 25 females, and 9 individuals of unknown sex and it is currently located at the Panum Institute, University of Copenhagen, Denmark (Irish 2005).

*C-Group* (CGR n = 62)

The C-Group (2200-1450 BCE) is considered an indigenous Nubian development, and the members of this culture are believed to be biologically related to the previous A-Group peoples (Carlson and Van Gerven 1977, Adam 1981, Martin et al. 1984, Johnson and Lovell 1995, Irish 2005, Irish and Konigsberg 2007). C-Group populations reoccupied earlier A-Group sites in Lower Nubia and followed similar subsistence and burial practices, albeit with a greater reliance on grain agriculture and cattle herding (Johnson and Lovell 1995, Shaw 2000). It is probable that the A-Group did not disappear from Lower Nubia as a result of Old Kingdom military action there. Instead, A-Group populations retreated to adjoining semi-desert regions and re-entered Nubia as C-Group during a time of Egyptian decentralization (Morkot 2001).

C-Group individuals display higher rates of oral pathologies (AMTL, macrowear, abscessing, and dental caries) compared to their A-Group predessecors, which supports the assertion for agricultural intensification in the latter (Beckett and Lovell 1994). This may be related to the deteriorating climactic conditions that characterize most of C-Group's archaeological existence: exceptionally low floods have been described from the reign of Sixth Dynasty king Merenra (2287-2278 BCE) to the closing years of 12th Dynasty king Amenemhat I (1986-1956 BCE) (Butzer 1976). Intense cultivation of millet and/or reliance on cattle may have been an adaptive shift that allowed C-Group populations to adjust to conditions of increased aridity and desertification. The C-Group sample in this study is comprised of 19 M, 22 F, and 21 U. Excavation and curation information are the same as for the A-Group above.

**Classic Nubian cemeteries (1750 BCE-550 CE)**

*HK27C* (HCG n = 47)

HK27C describes the locality of a Middle Kingdom (2055-1650 BCE) cemetery at Hierankopolis in Upper Egypt. Although it is located in Egypt, 23 of the original 100 burials discovered at HK27C have been culturally identified as ethnic C-Group Nubians. Many burials display unambiguous Nubian cultural affiliation, which includes distinctive superstructures over the burial shaft and traditional Nubian dress, jewelry, hairstyle, and even bone tattoos on the deceased (Irish and Friedman 2010).

Nubians residing in Egypt at that time was not an unusual phenomenon, considering the political circumstances. During the preceding First Intermediate Period (2160-2055 BCE) the centralized Egyptian state fragmented into competing regional polities. Control of Lower Nubia was ceded to C-Group mercantile elites who came to dominate the vital and lucrative trade in luxury and manufactured goods between Theban Egypt and Kerma, further down south along the Nile (Hafsaas-Tsakos 2009). This situation created conditions of increased fluidity and population interactions along the Egypto-Nubian border. Egyptian officials of the Old Kingdom may have remained in Lower Nubia during this period in the service of the king of Kush or local C-Group chieftains, and groups of Nubians moved north to live, die, and be buried in Egypt as either tradesmen, artisans, army mercenaries, or policemen (Trigger 1976, Bourriau 1991, Zakrzewski 2007, Bard 2008, Irish and Friedman 2010).

The HCG individuals (14 M, 26 F, 7 U) can provide particularly useful information about cultural interactions during this time of transition. Some of the mortuary elements associated with the C-Group burials, such as sandstone or mud brick superstructures, and the hairstyle during the person's lifetime, were obvious and externalized diacritica of Nubian ethnic identity in an otherwise Egyptian surround. Additionally, based on burial wealth, the HCG individuals appear to have been relatively affluent members of their society and therefore cannot be considered slaves, prisoners, or second-class citizens of any sort (Irish and Friedman 2010). Considering that at least part of the cemetery's temporal span coincided with extensive Egyptian campaigns in Lower Nubia during the 12$^{th}$ Dynasty, HCG may help further explore cultural interaction and notions of ethnic identity during a time that we have little information about.

*Pharaonic* (PHA n = 38)

Like the previous A- and C-Group samples, the PHA sample in this study was originally unearthed between Farras and Gamai by members of the Scandinavian Joint Expedition. The 38 individuals (15 M, 14 F, 9 U) represent Pharaonic Nubians, ca. 1650-1350 BCE (Irish and Konigsberg 2007). Although the Pharaonic sample may contain Egyptian colonists, especially in later, New Kingdom horizons (Calcagno 1986), Mahalanobis $D^2$ values derived from dental non-metric analyses indicate close genetic affinities between the C-Group and PHA samples (Irish and Konigsberg 2007). The sex composition of the PHA sub-sample is 15 males, 14 females, and 9 individuals of undetermined sex.

*Kerma and Kawa* (KER n = 63, KAW n = 37)

The archaeological site of Kerma is situated on the right bank of the Nile in Upper Nubia (north Sudan), and approximately 20 km south from the Third Cataract (Chaix and Grant 1993). Kawa lies approximately 40 km upstream on the same side of the river. The stretch of the Dongola between the two locales constitutes the widest and most fertile part of the floodplain south of Aswan and north of the Fifth Cataract. Consequently, the area has been a focus of human subsistence activities and has witnessed continuous habitation since at least the fourth millennium BCE (Khartoum Neolithic) (Trigger 1976).

Historiographical evidence embedded in Old Kingdom literary texts suggested that by the Sixth Dynasty (2345-2181 BCE) pastoral and mixed economy groups in the Dongola region had already coalesced into at least one important chiefdom in the area of Kerma. By the end of the Middle Kingdom in Egypt, the Kerma culture had developed into a powerful, centralized, and stratified state in control of the trade routes not only with Theban Egypt but also with the Hyksos in the Delta, west Africa, and Palestine (Smith 1998). The accumulation of wealth and the monumental architecture that characterized the Classic Kerma phase suggests a social organization at the level of kingdom, perhaps with several lesser subject polities, clients, or vassals (Trigger 1976, Bourriau 1991).

The KER sample in this study comes from the late, or Classic, Kerma period (3700-3450 BP). The economy of Kerma at that time was based on intensive agriculture and cattle breeding. The importance of cereal agriculture in ancient Kerman diet is archaeologically evidenced by the abundance of cereal funerary offerings found in tombs, the large number of bakeries and ovens in the town of Kerma, and the very large number of bread moulds and grinding querns there, as well as other contemporary sites (Chaix and Grant 1993). Furthermore, isotopic analysis of human skin and bone showed that Middle Kingdom Egyptians shared identical mean values of $\delta^{13}C$ and $\delta^{15}N$ with Classic Kermans. Thus both peoples had similar diet, i.e. one based on emmer wheat and barley cultivation (Iacumin et al. 1998). Additional dietary information is provided by the paleofaunal record from Kerma. The overwhelming majority of faunal remains (over 90%) belonged to domestic animals, mainly oxen and caprines (sheep and goat), indicating that the inhabitants of Kerma were almost exclusively breeders with hunting playing a very minor and unimportant part (Chaix 1993). The slaughtering of many young calves and juvenile animals together with the very large number of bucrania burials (up to 500 bucrania were found in a single burial) suggests that the animals played a very important ideoreligious role in Kerman society, and were most likely kept for their milk and not eaten for meat. This practice also has parallels with modern pastoralist groups in Africa and Asia (Chaix 1993).

The 63 individuals in the sample (23 M, 34 F, 6 U) were originally collected by Reisner and associates for a joint Harvard University and Boston Museum of Fine Arts expedition (Irish 2005). Of the 63 individuals, 45 were non-corridor burials (prime and sub-prime), while 16 were found in corridors and are presumably sacrificial. The remaining two burials are from the Meroitic period. Univariate (independent samples t-test) and multivariate (discriminant function) analyses of dental non-metric traits show no statistically significant differences between corridor and non-corridor burials. This suggests that the individuals from the sacrificial and sub-prime burials were members of the same population. The 37 individuals (16 M, 13 F, 8 U) in the KAW sample were excavated by the SARS near Kawa, 70 km (43.5 m) upstream from Kerma, and belong to the early Kerma period, or Kerma Ancien (Irish 2005).

*Soleb* (SOL n = 32)

Soleb is situated between the Dal and Third Cataracts in Upper Nubia. The 32 individuals in this sample (15 M, 8 F, 9 U) were excavated between 1957-1963 by Schiff-Giorgini for a joint French-Italian expedition and are currently curated at Musee de l'Homme in Paris, France (Irish 1998b). Soleb was a fortified temple-and-town built by the 18th Dynasty pharaoh Amenhotep III for worship of him and his wife (Bonnet 1991, Irish 1998b). Temple-towns like Soleb may have been built to accommodate an expanding population from Egypt or take advantage of the fertile agriculture in the Dongola region. Their ethnic make up is unclear but it is thought they were populated by a mixture of Egyptians, Nubians, and/or Egypto-Nubians (Irish 1998b, Morkot 2001). In the case of this sample, tooth size apportionment analysis indicates that the SOL individuals are characterized by larger and morphologically more complex teeth than other contemporaneous Egyptians and Nubians (Irish and Hemphill 2004). Teeth of large size and complex morphology are a characteristic of sub-Saharan populations. On the other hand, dental non-metric analyses show that SOL has close affinities with contemporary Egyptians as well as later Meroitic and post-Meroitic Nubians. These results suggest that by the time of New Kingdom expansion into Upper Nubia, both Nubians and immigrant Egyptians belonged to the same population (Irish 1998b).

## Late Nubian cemeteries (100 BCE-1350 CE)

*Meroitic* (MER n = 94), *Kushite (*KUS n = 63)

The KUS subsample is dated 600 BC-550 AD (15 M, 28 F, 20 U) and it represents early (Napatan) and late Meroitic specimens from Kawa in the Dongola region, and Gabati. The latter is located 40 km (24.9 m) north of the ancient Kushite royal city and cemeteries of Meroe in Upper Nubia. The Meroitic period of Nubian history witnessed the greatest agricultural innovations since the introduction of domesticated wheat and barley into Nubian around the time of the transition from the Neolithic to the A-Group culture (Fuller 2004). Domesticated sorghum in Meroitic Nubia provided a third, summer crop and made agriculture a year-round activity (Wetterstrom 1993b, Fuller 2004). Additionally, the introduction of the *saqqia* (water wheel) around the same time facilitated the terracing of previously inaccessible locations and lead to an expansion of overall agricultural land (Martin et al. 1984, Fuller 2004). Herding of cattle, sheep, and goats provided the second most important economic activity for ancient Meroites, as was the case for their Nubian predecessors before them (Martin et al. 1984). Cattle were used for agricultural labor and for their milk and were not eaten for meat.

Other crops harvested by the Meroites includes numerous fruits and vegetables such as beans, lentils, watermelon, dates, mangos, and citrus products (Martin et al. 1984).

Archaeobotanical remains from Gabati includ two-row, hulled barley (*Hordeun sp*), sorghum (*Sorghum sp*), cereal straw, and figs (*Ficus sp*). The admixture of materials was apparently derived from crop processing byproducts used as temper in Meroitic mudbricks (Edwards 1998). The MER sample (36 M, 45 F, 13 U) was collected by the joint effort of the Joint Scandinavian Expedition and the University of Chicago near Semna; it is meant to represent post-Kerma populations in Lower Nubia (Irish 2005).

*X-Group* (XGR n= 63), *Christian* (CHR n = 41)

Royal burials cease at Meroe ca. 360 CE and Nubia broke up into smaller polities and petty kingdoms collectively known as the X-Group (Bard 2008). The folk religion during this time may have been an amalgam of Isis worship, Christian elements, and vestiges of the old Meroitic imperial cult. When Christianity was introduced in the Sixth Century AD, it was easily adopted by the inhabitants, with Christian kingdoms arising instead (Adams 1970). Subsistence strategies during this period did not change much compared to the previous Meroitic, and consisted of intensive agriculture of barley, emmer wheat, and sorghum supplemented with animal husbandry, and various fruits and vegetables (Martin et al. 1984). Carbon isotope analysis showed considerably less negative $\delta^{13}C$ values for late Christian individuals compared to earlier Kermans. This important finding may indicate a shift towards C4 plant dependency during this time (Iacumin et al. 1998). Although no conclusive statements can be made at this point, it is likely that sorghum and millet agriculture (the classic C4 plants) may have been more optimal for late Christian Nubians due to environmental degradation and military pressure from encroaching Muslim neighbors, especially from the direction of Egypt.

Both XGR and CHR samples came from the same area and excavation in Lower Nubia as the MER sample above. The XGR is composed of 29 M, 18 F, and 16 U and is dated to 350-500 AD, while the CHR sample is composed of 17 M, 22 F, and 2 U and is dated to 550-1500 CE (Irish 2005).

# CHAPTER 5

# METHODS

The methods of analysis in this thesis are largely directed by the type of data used and the nature of the research questions posed. The data set in this analysis is composed of numerical values (from one-four) representing dental caries severity per tooth. Dental caries in the archaeological record is the sum of the pathological manifestations at a single point in time (death of the tooth, or the animal bearing the tooth) of an infectious disease *process* that can, sometimes, last for the entire life of the individual. The grouping of this process into ranked, distinct categories may thus seem somewhat arbitrary. However it is necessary if the data is to become suitable to statistical analysis. The latter requires, among other things, that the dependent variable(s), i.e. the one we wish to evaluate change in, is represented by numerical values (Gravetter and Wallnau 2008). At the same time, the skeletal population is composed of 32 different samples spanning a total of ~ 15000 years, thus making the population ideal for comparative analysis of caries inter-sample variability over time.

Egyptian and Nubian caries frequencies have been shown to vary greatly depending on the samples selected for study (Rose et al. 1993), and previous scholarship has underlined the fact that Egyptian inter-sample caries variability between contemporaneous cemeteries superseded caries differences over large periods of time (Hillson 1979). Thus most, if not all, of the research questions in this thesis were constructed with the latter in mind, i.e. they are an attempt to better explore within-sample caries differences in the population. In order to better explore inter-sample caries variability, the 32 samples were grouped into a number of categories, each corresponding to an economic, cultural, or historical phase in Egyptian and Nubian history. The remainder of this chapter is concerned with the reasoning behind the construction of these categorical variables, the statistical techniques undertaken for comparisons, as well as some issues concerning dental (and skeletal) representation in the archaeological record.

**Economy, Period, Region, Country, Sex, Age, Status**

As was discussed in Chapter Three, changes in caries frequencies represent a dependable measure of the carbohydrate component in the diet, and can thus provide information about dietary shifts from hunting and gathering to agriculture. Overall, caries rates are lower in preagriculturalist hunter-gatherers-fishers than agriculturalists (e.g. Turner II 1979, Hillson 2008). One of the research questions seeks to evaluate this subsistence-based assertion in the context of the expanded data set offered by this analysis. Testing of this hypothesis was the main reason for the construction of the categorical variable Economy and its three factors, Preagriculturalist, Agriculturalist, and Intensive Agriculturalist.

Inclusion of samples within each of the three groups was based on the existing archaeological and cultural/historical record regarding mode of subsistence. This latter is extensively discussed in chapters Two and Four. In review, the Preagriculturalist sub-component is composed exclusively of Mesolithic and Neolithic Nubian hunter-gatherer-fishers. All later samples practiced various degrees of subsistence agriculture based on the cultivation of emmer wheat, barley, and to a lesser extend, millet and sorghum.

Inclusion into the Intensive Agriculturalist category was based on archaeological evidence for practices of agricultural intensification for the respective samples, as these are discussed in Chapter Three. In Egypt, the Intensive Agriculturalist category includes mostly Ptolemaic and Romano-Byzantine samples. The same category in Nubia is again represented by later samples from the Meroitic, X-Group, and Christian cultural phases. The results of comparisons of caries prevalence by factor for Economy are expected to agree with what is generally observed elsewhere; that is, an increase, perhaps gradual, from the Preagriculturalist to the Intensive Agriculturalist stage.

In order to explore chronologically-based inter-group differences in more detail, the next comparison is concerned with caries differences between the broad cultural units the samples belong to. The categorical variable Period is composed of Prehistoric, Predynastic, Early Nubian, Dynastic, Classic Nubian, Late Dynastic, and Late Nubian sub-components. These groupings are thought appropriate in the light of previous research on dental disease in Egypt and Nubia. As has been discussed elsewhere in this work, caries rates in Egypt and Nubia remained generally low until the later periods (Greco-Roman and Late Nubian) when agricultural innovations and a widening of trade networks increased both availability and consumption of cariogenic foods. As mentioned at the beginning of this chapter, statistically significant differences in caries rates existed among contemporaneous, proximal, and culturally related Egyptian populations (Greene 2006), as well as temporally and geographically separated groups, both in Egypt and Nubia (Armelagos 1966, 1969, Ibrahim 1987, Beck and Greene 1989, Beckett and Lovell 1994). Thus caries comparisons for Period are expected to reveal information about dietary change not discernable in the comparisons for Economy. For example, the economic sub-category of Agriculturalist includes Predynastic, Early Nubian, Dynastic, and Classic Nubian sub-components of Period. Statistical analysis of caries variance across factors within the latter variable can indicate significant differences, or absence thereof, and thus partition unexplained variance in a more detailed way than under the Agriculturalist label.

Further comparisons are concerned with geographic location. Lower Egypt, Upper Egypt, Lower Nubia, and Upper Nubia constitute distinct geographical regions marked by variations in rainfall and width of the Nile, and are delineated by distinct fluvial geomorphologic features such as the Four Cataracts and the Batn el Hajar in Lower Nubia. From very early in Egyptian history Lower Egypt demonstrated regional idiosyncrasies compared to the rest of the country. The Qarunian lithic industry (ca. 7085-6008 BCE) in Lower Egypt had more in common with Siwan assemblages and the Libyo-Capsian lithic complex from Haua Fteah, and differed significantly from contemporary Nilotic assemblages (Hayes 1969, Hassan 1978). Lower Egypt also witnessed more extensive population movement and influx than the rest or Egypt, especially during the Second Intermediate, Late Dynastic, and Greco-Roman periods. In Nubia, biological affinity analyses based on discrete dental traits indicated that late Neolithic groups from the Lower and Upper parts of the country were not related biologically (Irish 2008).

Furthermore, the four regions are characterized by different dietary practices and rates of dental disease (Ibrahim 1987, Greene 2006). Whereas Egyptians relied on staples derived mostly from emmer wheat and barley, Nubians practiced millet and sorghum agriculture and relied more heavily on domesticated cattle than their Egyptian counterparts. Caries experiments on caries-active Osborne-Mendal rats have shown that cooked and uncooked sorghum is significantly less cariogenic than cooked and uncooked wheat and maize, even when the sorghum is infused with 20% sucrose (Schmid et al. 1988). For these reasons, the samples in this study have been grouped into two additional categorical variables, Region (see above) and Country (Egypt and Nubia). Today Nubia is a geographical region shared by the two nation-states of Egypt and Sudan. Therefore the term 'Country' applies to Nubia as a descriptive term to serve the purpose of statistical analysis and comparison. Results from caries comparisons in these categories can provide useful information that may help re-evaluate what we know about regional variability in dental disease.

Other comparisons are concerned with differences in caries prevalence according to sex and status, whenever this information was available for the samples in question. The reasoning behind these comparisons is explained more fully in Chapter One and again Chapter Three of this thesis. Briefly, caries tends to affect females in agriculturalist groups more than males (Larsen et al. 1991, Lukacs 1996, Greene 2006), it is an age-progressive disease that afflicts members of middle and older age groups more than members of younger age groups, and caries rates can vary considerably between members of elite and lower classes in agricultural populations. It is thus very important that caries studies in archaeological populations provide statistical information on caries frequencies according to sex and age groups (Hillson 2001, 2005). Overall, the results of sex and age comparisons in this study are expected to conform to the general trends mentioned just above. However, variability in regional caries frequencies by sex may help elucidate patterns in differential access to resources and other aspects of economic and perhaps other aspects of the social and economic organization.

The composition of the skeletal population by sex is explained in Materials and can be seen in Table One. Even after removal of the unsexed (U) category, the ratio of males/females (676/793) provides a reliable sample size for each sex. This is not the case for age and status groups. Children (0-10 yrs) and sub-adults (10-18 yrs) comprise 7% and 8% of the total sample, respectively, and thus cannot be considered reliable representations of the populations from which they derive, especially over the long temporal span covered in this study. Additionally, 126 from the 133 individuals in the Children group (94.7%) are of unknown sex; thus no assessment of sexual dimorphism for caries can be undertaken for this age group. A considerable portion of unsexed individuals (63 in 157) also exists in the Subadult category. Exclusion of the latter in sex comparisons will decrease the Subadult component and reduce the reliability of caries comparison results for that group. It is only in the Adult category that comparisons f sex dimorphism in caries prevalence can be conducted with any degree of confidence. Given the above, the overall results of caries comparisons for age in this thesis must be viewed with caution.

Information on social status exists for 13 of the total 32 cemeteries. The lower class component (312) is derived from two Predynastic cemeteries at HRK and NAQ; the middle class individuals (134) come from one Late Dynastic (GIZ) and one Roman

(HES) cemetery; the upper class (491) component can be considered the only 'true' diachronic category representing eight Egyptian (ABP, ABD, THE, QUR, TAR, SAQ, LIS, OKH) and one Nubian (SOL) cemetery with a time range from Predynastic Egypt to Pharaonic Nubia. Since the lower and middle class samples are small and temporally restricted, the results of status comparisons cannot be at taken at face value. Rather, social status comparisons are provided as rough approximations of differences for some of the periods involved. These, like comparisons based on age, cannot be considered a true representation of the actual dietary conditions among different segments of the population over the entire period covered by the study.

**Dental representation and prevalence in the archaeological record**

The etiology, epidemiology, and paleopathology of dental caries have been discussed extensively in Chapter Three. This section is concerned with the procedures used for scoring, recording, and analyzing dental caries, as well as some general problems related to the estimation of dental caries prevalence and distribution in archaeological populations. Most epidemiological studies of caries in living human populations use the Decayed, Missing and Filled teeth index (DMF), which is derived by adding up the total number of DMF teeth per individual. The caries experience of a population can then be expressed as its mean DMF score (Hillson 1996, 2000, 2001). In archaeology, reliability of the DMF index as true depiction of caries occurrence is compromised by the differential preservation, and representation, of different classes of teeth in skeletal populations. Since dental caries rates are affected differentially by such factors such as sex, age, status, tooth type, tooth class, and jaw, it is rare that an older individual will be interred with his/her full complement of teeth (Hillson 2001).

The determination of ‘true’ caries frequencies becomes problematic because random tooth loss causes dental caries frequencies to deviate from their true value (Duyar and Erdal 2003). The DMF index, in particular, is not appropriate for estimating caries frequencies in archaeological populations because, among other things, it assumes that all tooth loss during life (antemortem tooth loss, or AMTL) is due to caries. However, teeth can be also lost antemortem to periodontal disease (PD), trauma, or as a consequence of continuous eruption in heavily worn teeth; and after-death tooth loss (postmortem tooth loss, or PMTL) can occur during excavation, secondary burial, or by accidental damage to the skull (Moore and Corbett 1971, Whittaker et al. 1981, Hillson 1996, Cucina and Tiesler 2003, Duyar and Erdal 2003). The ratio of dental caries-induced tooth loss to PD-induced tooth loss, in particular, is expected to vary considerably between populations, given the large contrasts in diet and behavior that are evident in archaeological material (Hillson 2001). If a distinction is not made between the two pathologies, erroneous attribution of PD tooth loss as loss due to caries will tend to elevate dental caries rates in older ages that are most likely to be affected by either, or both diseases (Whittaker et al. 1981).

Instead of the DMF index, commonly used alternatives in archaeological contexts express dental caries frequencies as the percentage of carious teeth to the total of observed teeth (also known as caries count, rate, or percent), or the number of carious individuals as a percentage of the total skeletal population, also referred to as individual count (Nelson et al. 1999, Hillson 2001, Duyar and Erdal 2003). Dental caries count is more appropriate in situations where there is a concern with the differential effect of dental disease on tooth classes, size of the lesion, location on the tooth crown, or jaw, which is the case in most archaeological populations. Additionally, the caries tooth count method tends to increase sample size since the calculations are based on the total of observed teeth, rather than the number of individuals (Lukacs 1992).

Some researchers have preferred a variation of caries count, where dental caries rates are calculated separately per tooth class by dividing the number of the carious teeth of that class by the total number of that class present in the skulls, multiplied by 100 (Moore and Corbett 1971, Whittaker et al. 1981, Powell 1985, Kerr et al. 1988). Others provided data of carious frequencies per individual tooth between different population groups (Walker and Erlandson 1986). Useful information can also be derived from the average number of carious teeth per individual. This last is similar to the DMF index for living populations, and should be the logical approach in caries rates analyses when there is considerable individual variation of caries experience within the population (Saunders et al. 1997). In populations with similar dental caries counts, individual differences may indicate cultural preferences that expose some members to higher cariogenic risk than others (Schollmeyer and Turner II 2004).

However, the aforementioned statistical representations of caries frequency rates still do not address the issue of ante- and post-mortem tooth loss. As a result, some researchers have applied correction factors to compensate for the potential misrepresentation of true caries rates caused by AMTL and PMTL. Costa Jr. (1980)

compared incidence rates for caries and abscesses in three archaeological populations from Point Hope and Kodiak Island, Alaska. In order to account for AMTL the author calculated correction factors for each sex, age, and site subsample by multiplying the average number of carious teeth per individuals times 32, and dividing that by 32 – average AMTL per individual. The correction factor was then multiplied by the total number of caries and abscesses in each subsample (Costa Jr. and Raymond 1980).

Whittaker and coworkers (1981) reported on prevalence and distribution of caries in 512 Romano-British skulls from the Poundbury cemetery in Dorset, England. The authors provided information on the number of carious teeth per class as percentage of total teeth by class *at risk*, i.e. including those lost ante and postmortem, and the number of carious teeth per class plus AMTL as a percentage of teeth of that class at risk (i.e. AMTL plus PMTL). Kelley and coworkers (1991) used a variation of the DMF index referred to as the Decayed and Missing (DM) index. In their study of AMTL in five early northern Chilean groups Kelley et al. (1991) calculated their index by dividing the total number of carious teeth plus total number of AMTL over the total number of teeth plus total number of AMTL, multiplied by 100. According to Kelley and co-workers (1991), the DM index produces a more comprehensive estimation of dental health by adjusting caries rate for AMTL loss, regardless of whether their loss was due to attrition or disease.

Saunders and coworkers (1997) used a modification of their DM index derived from the number of carious plus restored sockets as a percentage of the total number of teeth plus resorbed sockets. A comparison between caries percent and the authors' index on a 19$^{th}$ century cemetery sample from southeastern Ontario showed that the DMF underestimated while the DM overestimated caries rates in that population (Saunders et al. 1997). These results are most likely secondary to the fact that caries percent (or rate) does not account for AMTL, while the DM index assumes that all AMTL is the result of caries. While the latter assumption may be appropriate for populations that experience low rates of wear and periodontal disease (Saunders et al. 1997), in other situations the DM index is likely to inflate the caries rate because it does not differentiate between caries-induced and PD-induced tooth loss.

Lukacs (1992, 1995) calculated a 'caries correction factor (CCF)' based on the difference in pulp exposure caused by attrition and that caused by caries. By assuming that AMTL is a result of one or the other, the author proceeds to calculate percentages of teeth with exposed pulps due to attrition versus those from caries. If the latter percentage is multiplied by the total number of AMTL in the series, it will produced a figure that can then be added to the total of carious teeth and thus be closer to the 'true' rate of caries prevalence by only including AMTL due to caries. When the corrected rate was applied to a sample of prehistoric Harappan agriculturalists, the overall caries rates almost doubled, especially in the females of the group (Lukacs 1992, 1995). Similar results have also been produced for a sample of Iron Age agriculturalists from the Samad oasis in Oman. When the CCF was applied on uncorrected caries frequencies there (i.e. excluding AMTL), individual and tooth caries counts rose from 35.5% to 39.4% and from 18.4% to 32.4%, respectively (Nelson et al. 1999).

However much of an improvement the CCF may represent over previous methods for calculation of AMTL, the method relies upon the critical assumption that all carious disease is related to dietary behaviors. As was discussed in Chapter Three, cariogenicity in the human mouth can also be affected by physiological and genetic factors interacting in the chemical process between plaque bacteria and carbohydrates. Females in particular may be more predisposed to caries as a result of hormonal fluctuations due to life cycle and reproductive events such as menstruation, pregnancy, birth, and lactation (Lukacs and Largaespada 2006, Lukacs 2008). Although caries is ultimately the culprit leading to loss of tooth during life, its prevalence in the latter scenario is affected by extra-dietary components not detectable when all AMTL is attributed to diet-related factors.

Additionally, Erdal and Duyar (1999) criticized the CCF index because the latter did not take into account the differential preservation for anterior and posterior teeth. Because of the morphological and root differences between anterior and posterior teeth, the former are more likely to be lost postmortem. At the same time, posterior teeth are more prone to cariogenic attack and antemortem loss. The net result is that the observed ratio of anterior/posterior teeth in cemetery samples can vary considerably from the 0.6 ratio of a complete mouth in a living human with all teeth present. This fact can influence interpretation of caries rates in archaeological populations. Some support for this conclusion is provided by caries data from medieval Croatians, where statistically significant differences existed in caries frequencies between maxillary and mandibular teeth (Vodanovic et al. 2005). For these reasons, Erdal and Duyar (1999) proposed their own ‘proportional correction factor (PCF)’ which multiplied a) carious anterior teeth by three-eights b) posterior carious teeth by five-eights. These two figures were then added to the total number of carious teeth; the figure from these calculations can be used to adjust the CCM to better represent true caries rates in a given population (Erdal and Duyar 1999, Duyar and Erdal 2003).

It must be clear from the discussion so far that there is not a single approach that can adequately represent rates of carious AMTL in archaeological material. As has been discussed in Chapter Three, the extent of enamel demineralization caused by caries bacteria depends on the interaction of such diverse factors as the amount, type, and frequency of carbohydrate intake, prevalence of plaque bacteria in the mouth, rates of attritional tooth wear, food texture and preparation techniques, mineral content of ingested food and water, variability in oral cleansing habits, host susceptibility and tooth genetics, and variations in crown morphology (Hillson 1979, Legler and Menaker 1980, Powell 1985, Thornton 1991, Hartnady and Rose 1992, Deeley et al. 2008, Tannure et al. 2012). Considering the differential preservation of dental material in archaeological contexts, it is not always possible to fully account for all of these factors. Additionally, a collection of archaeological material can be exposed to various preservation and excavation biases and it does not necessarily represent a random sample of the original living population (Hillson 2001).

Moreover, dental caries rates can be influenced by cultural preferences and food preparation techniques that are not clearly discernible based on dental findings alone. For example, variations in grinding techniques between culturally related agricultural groups can result in higher rates of approximal caries in one of them, which could be secondary to the production of finer, highly processed foodstuffs that tend to adhere longer in the interproximal spaces between teeth (Schollmeyer and Turner II 2004, Lafranco and

Eggers 2010). Further, prevalence of dental caries and other oral pathologies within a group can vary according to age, status, and sex in relation to ideo-religious beliefs and culturally imposed practices in food acquisition, distribution, and consumption (e.g. Molnar and Molnar 1985, Meiklejohn et al. 1988).

These profound variations in the etiology and epidemiology of dental caries over time have lead some authors to question the validity of any attempt to correct for AMTL in the first place (Brothwell 1963). Others have pointed out that the various indices for AMTL are not standardized and thus do not facilitate inter-sample comparisons. Additionally, there is considerable variation in the way these studies address the effect of AMTL versus PMTL in caries frequency (Schollmeyer and Turner II 2004). PMTL is important because anterior teeth are single rooted and thus more likely to be lost post mortem. In a medieval Scottish cemetery sample, 63% of all PMTL was made up of incisors and canines; these also happen to be some of the least cariogenic teeth (Kerr et al. 1990). Since posterior teeth are less likely to be lost postmortem, archaeological collections that have poor anterior teeth preservation will have artificially inflated caries rates (Hillson 1996). Costa Jr. (1980) mentioned a correction for PMTL in caries per individual, but does not show how the latter was calculated. Kerr et al. (1990) provide figures for PMTL per age group as a percentage of the teeth present plus AMTL and PMTL, but do not attempt any comparisons. Moreover, it is not clear what should be done with any PMTL values derived from these calculations. If PMTL is considered non-carious, then the corrected tooth number could be added to the total number of teeth observed in order to decrease caries frequencies by adding, presumably, non-carious teeth.

In the latter case, the assumption behind PMTL corrections is that all PMTL represents non-carious teeth. Diagnosis of AMTL versus PMTL is based on the condition of the socket and the periodontal bone that housed the tooth. Sockets with resorbed periodontal margins exhibit signs of repair after loss of tooth, whereas in teeth lost post mortem the socket remains in an open position, with thin, wafer-like margins (Vodanovic et al. 2005). The latter situation however does not exclude the possibility that some teeth may have been carious during life and were lost postmortem, for teeth lost immediately before death can be confused with those lost after death since there is very little time for healing of the socket. Even though this type of confusion in most cases is insignificant (Turner II 1979), any 'ideal' PMTL correction factor should be able to differentiate between carious and non-carious PMTL. When loose teeth are found in unambiguous association with the interred individual, these could be evaluated for pulpal exposure in accordance with Lukacs' (1992, 1995) method applied to AMTL. In other situations, counting all PMTL as non-carious may lower caries rates in the population.

## Dental caries methods

In view of the above, analysis of dental caries frequencies rates provided herein should be viewed as *minimal estimates* of dental caries prevalence (Turner II 1979) and not as absolute evaluation of caries changes over time in the living populations represented by the cemetery samples. No attempt is made to compute a correction factor for AMTL. Lukacs (1996, p 148) stated that application of CCF is ‘absolutely essential’ for skeletal series that display high AMTL, which is not the case here (see Results). According to previous discussion, the most complete AMTL correction would be the CCF adjusted by Erdal and Duyar’s (1999) PCF for anterior and posterior AMTL rates. However, no information is available on caries-induced vs. PD-induced pulpal exposure in this skeletal population.

Equivocal results in the remaining mathematical corrections for AMTL propelled this analysis to follow other authors of caries prevalence studies who treated all ante and postmortem loss as missing data, which was then excluded from comparisons between the different groups (Schollmeyer and Turner II 2004). However, separate AMTL frequencies are provided under the premise that there is value in comparisons of AMTL rates between samples. For that reason, statistical tests for differences in mean AMTL rate were also undertaken. If AMTL represents the combined effect of caries and periodontal disease in a population as discussed earlier, then changes in AMTL must be addressed for a more complete picture of dental caries prevalence in the population.

The dental caries frequencies used in this thesis were recorded by Dr. Joel D. Irish (Research Centre in Evolutionary Anthropology and Paleoecology, Liverpool John Moores University). Previous studies on caries prevalence in archaeological samples have shown that inter-observer error is insignificant between sets of caries data taken at different times by the same observer (Whittaker et al. 1981, Kerr et al. 1988, 1990). Therefore the dataset in this analysis is thought to be both reliable and valid. Caries severity was scored by the same worker on a scale from one to four, according to

Koritzer's (1977) caries grade levels. The first category is defined as a small pit or fissure lesion; the second category is represented by a moderate-sized pit, or fissure, or a smooth-surface lesion up to moderate size; category three includes any lesion that endangers the pulp, and category four entails exposure of the pulpal core (Koritzer 1977). This scoring scheme is not by any means exhaustive. For one, it does not account for incipient, or precavitated, lesions. Second, caries progression is a continuous process that may last late into life. Thus arbitrary grouping of such process into distinct categories of severity may leave out unaccounted variance and skew results. Finally, Koritzer's (1977) method provides no evaluation of gross caries damage since the latter are included in the generalized category 'four'. Gross caries can remove significant areas of tooth surface and it is expressed on a gradient that is not described well within only four categories (Hillson 2001).

*Caries location*

In studies of caries prevalence it is customary to record caries as present or absent for each tooth. However, the complex etiology and differential distribution of caries has given rise to several methodological approaches for describing the location of caries lesions on tooth surfaces (Hillson 2001). In their impactful comparative study of Anglo-Saxon and other British caries frequencies, Moore and Corbett (1971) used three main groups of lesion sites (occlusal, interstitial, buccal) each with three subcategories, for a maximum of 12 possible loci. Molnar and Molnar (1985) scored the presence of caries in their prehistoric Hungarian samples as '…occlusal, interproximal, root, and massive carious lesion of several tooth surfaces (p. 54)'. Innovatively, the authors classified root caries in two separate categories, cervical-bound and coronal-bound root caries (Molnar and Molnar 1985). In their study of caries prevalence in modern rural Kenyans Manji and co-workers (1989) used two grades of expression for smooth surface, occlusal, and approximal surface caries, two grades for coronal caries involving the dentine, and two more grades of expression for root caries (Manji et al. 1989). More recently, Hillson (2001) has proposed that information on caries frequencies be presented as a number of different percentages of occlusal, pit, contact area, and gross contact area caries, over the totals of the surviving crown elements for each respective category (Hillson 2001).

Overall, the two broad categories that describe dental carious lesions according to location are coronal and root caries. This thesis is concerned exclusively with coronal caries. Caries frequency data was collected as supplementary to a greater project seeking to evaluate biological relationships in the same population based on standard ASUDAS methods for grading dental non-metric traits. Some information (root caries frequencies) was omitted and some other data was simplified for the sake of statistical expediency, and in order to fit within the analytical scope of this thesis. In regards to the latter, caries location has been recorded only once per tooth as occlusal (O), buccal (B), lingual (L), mesial (M), or distal (D). The greatest handicap of recording caries once per tooth is that this method does not account for the possibility that a tooth may be affected by more than one carious lesion. This can result in underestimation of tooth caries prevalence in a population (Hillson 2001). In contrast, individual caries frequencies are calculated from counts of single specimens and can be thus thought to be a truer description of population caries rates than tooth caries (Hillson 1996). The discussion on caries location thus far is a good reminder that thesis results must be viewed as *estimation* of caries prevalence and the need to analyze more than one caries indicator, hence the emphasis on tooth caries, individual caries, and AMTL.

## Statistical methods

The purpose of this thesis is to explore differences in caries prevalence in a large number of ancient Egyptians and Nubians. For that purpose, the skeletal population was organized into the categorical variables Country, Region, Economy, Period, Sex, Age, and Status as defined above. This type of data organization becomes very suitable to application of parametric and non-parametric statistical techniques. A combination of these can be used when one wishes to evaluate the significance, or lack thereof, of the changes in the mean of a dependent, interval variable as these are affected by the changes in the mean of an independent, categorical (or grouping) variable (Tabachnick and Fidell 2006). All statistical analyses, including the figures and various graphs in Results, were carried out using the graduate pack of SPSS v.19. Windows Excel 2008 for Mac was used to calculate sums and percentages for teeth and individuals, and provided the format for most of the tables seen here.

Parametric statistics are suitable to analyses where sample data is used to make inferences to a population, or populations, whose statistical distributions are assumed to approximate normality (Howell 1995, Madrigal 1998, Norušis 2010). The relationship of population to sample is defined by the Central Limit Theorem (CLT) which states that the distribution of scores for a sample will begin to approximate a normal distribution, and align more with the distribution in the population as sample size gets larger (Hinton 2004, Gravetter and Wallnau 2008, Kinnear and Gray 2010). The overwhelming majority of cemetery samples in this study is well above the minimum recommended number of 30 individuals (Gravetter and Wallnau 2008), and the robust overall sample size inspired initial confidence that sample results using parametric statistics would reflect true caries rates in the actual populations. However, as will become evident shortly, and regardless of size, the distributions of the categorical variables in this study consistently violated important parametric assumptions in statistical testing, such as the requirements for normality and homogeneity of variance.

Non-parametric statistics make fewer assumptions about the data and can be used with small samples, categorical or ordinal data, or when there are serious departures from the required assumptions for parametric procedures (Norŭsis 2010). Instead of comparing differences in means or variances, non-parametric statistics compare how scores are ranked on an ordinal scale from smaller to greater, for different combinations of variables (Hinton 2004). By comparing ranks and not data, nonparametric statistics have the disadvantage of losing some information about the data (for example some ranks are tied, whereas their score may have been different) but there is little alternative in having to use them when sampling distributions are not normally distributed (Field 2009) – as is the case with this set of data. Therefore, this thesis assigns primacy to statistical testing using non-parametric techniques. Parametric results are presented in an appendix, for comparative purposes. In this way, a thorough and methodical approach is attempted at data analysis, at least from a statistical perspective. However this last point may be proved moot because, as will become apparent later on, these two sets of results differed little from each other.

**The independent variables**

In accordance with these general principles information in this thesis is provided on the caries parameters that are reported most often, tooth caries and individual caries. Tooth caries (also referred to as caries count) can be expressed as the percentage of teeth affected, and provides an estimate of caries prevalence in a population (Chamberlain and Witkin 2003, Papathanasiou et al. 2009). As mentioned above (*Caries Methods*, this chapter) each tooth in this skeletal population was scored only once for caries. Thus tooth caries was calculated as a percentage of the carious teeth over the total teeth observed for caries in each group. Although scoring caries once per tooth may underestimate true caries rates in a population, caries lesions increase the chances of additional lesions developing and inclusion of more than one lesion per tooth may lead to violation of the important statistical assumption for independence between variables (Sealy et al. 1992). In a similar fashion, Individual Caries represent the rate of carious individuals over the *n* of that group. Finally, AMTL percentages were calculated as the rate of teeth lost ante mortem over the total number of teeth of that group.

Parametric results on percentages for AMTL, Tooth, and Individual Caries, as well as the number of teeth observed (No. Teeth) and individuals in each group (n) may be seen on Appendix A. The same appendix also provides information on Mean Tooth

Caries, Mean Caries per Individual, and Mean AMTL. Determination of these indicators for the various groups was based on the totals for carious teeth (482) and teeth lost ante mortem (1720), respectively. On parametric tables, statistically significant differences in mean caries and AMTL are indicated with asterisks and other symbols; these are further explained in the appropriate section of the thesis. The non-parametric results in the body of the thesis provide information of number of ranks for each variable, as well as asymptotic significance values.

Whereas the variety of information presented in the various tables may at first seem confusing, it was thought appropriate in view of the diversity in caries reporting methods encountered in literature review and in order to offer as a broad perspective on caries differences as possible and allowed by the data. For example, while tooth caries provides an estimate of overall caries severity in a population, mean caries/individual provides a better idea about individual caries experience in that group. Dental health studies in past and present human populations indicate that most caries is shared by a restricted segment in the population (Meiklejohn et al. 1988, Matthesen et al. 1990). Thus high caries averages for individuals can indicate that the population is experiencing within-group caries on considerably differential levels. The latter would be especially true if the group also displayed low tooth caries: in a situation like this, almost all caries would be concentrated on few individuals. In contrast, caries experience in groups with high tooth but low individual caries averages could be more evenly spread out among the population. Thus examination of both tooth caries and caries/individual patterns offer a more complete dental profile for the population in question.

**Statistical tests**

The non-parametric statistical tests used to determine statistical significance in this analysis were the Kruskal-Wallis (K-W) test for independent measures and the Mann-Whitney (M-W) test. These tests are commonly used as non-parametric alternatives to independent measures analysis of variance (ANOVA) and independent samples *t*-test, respectively, in conditions when the data violates the assumptions that apply to parametric testing (Field 2009, Norŭsis 2010). The M-W test, together with the *t*-test, are used to compare two conditions of an independent variable on a dependent variable (Hinton 2004) and in this analysis they were used for all the comparisons involving the variables Sex and Country. Comparisons of categorical variables with more than two factors (e.g. Period, Region etc) require a different statistical approach.

In parametric statistics one could execute a series of *t*-tests but these multiple tests would accrue unwanted variability and increase the potential for committing Type I error, i.e. detecting significance where there is none (Hinton 2004). Instead of comparing differences in means, like the *t*-test, ANOVA techniques analyze the differences in variance as this is represented by within- and between-samples variance (Norušis 2010). The former provides a measure of how much difference can be expected by chance or accident, while the latter represents the systematic difference of the dependent variable when compared to the factors of the independent (Gravetter and Wallnau 2008, Hinton 2004). Additionally, ANOVA is equipped with powerful techniques for pairwise (post hoc) comparisons designed to contrast all different combinations of the independent factors (Field 2009). In this analysis, statistical significance between factors of the categorical variables was determined by the Games-Howell post hoc (see discussion in Parametric Assumptions below). All parametric results from *t*-test and ANOVA comparisons are presented in Appendix A. The non-parametric alternative of ANOVA, the K-W test, compares the observed ranking of dental caries scores for multiple factors against a hypothetical condition where no significant differences in ranks is to be found among samples. The K-W test lacks the comprehensive post-hoc capabilities offered by ANOVA, and post-hoc differences determined by using individual M-W tests. These results are presented in Chapter Six below.

Overall statistical significance for both parametric and non-parametric results is further evaluated by application of the Bonferroni correction. As briefly mentioned in the *t*-test discussion above, multiple comparisons using the same set of data increase the possibility of committing Type I error. One easy way to protect against such possibility is to adjust the observed significance level (i.e. the $\alpha$ level) for the number of comparisons undertaken. Bonferroni correction divides the $\alpha$ level by the number of comparisons, thus setting a smaller and more restrictive critical level. This process increases assurance that the cumulative Type I error (familywise error) will remain below the critical level originally chosen for the comparisons (Field 2009). For example, this analysis sets critical level for all comparisons at 0.05. For the categorical (independent) variable with the most factors, which is Period, the maximum number of comparisons undertaken is three x seven = 21. Thus the new critical level for statistical significance in Period is .05 / 21 = .002. The adjusted Bonferroni corrections for each categorical variable are mentioned in the respective sections in Results, as well as on the tables accompanying each comparison.

## Parametric assumptions

There are some general statistical assumptions that apply to all parametric techniques. Two of them, normality and interval level of measurement for the dependent variable(s), were briefly referred to at the beginning of the previous section. The requirement for normality is an extension of the fact that parametric statistics make inferences to populations whose own statistics are in many cases unknown. Thus, in order for the results of, say, a *t*-test to have validity, it is assumed that the sample mean is similar to the population mean. In hypothesis testing, the latter is customarily represented by the null hypothesis, or $H_0$ (Gravetter and Wallnau 2008). SPSS v. 19 provides several methods for assessing normality of continuous variables. Descriptive statistics for the three dependent variables in this study can be seen in Table Five below. One significant

**Table 5.** Descriptive statistics for the three variables

| | | Teeth with caries | Carious teeth per individual | Teeth missing antemortem |
|---|---|---|---|---|
| N | Valid | 1842 | 1753 | 1842 |
| | Missing | 0 | 89 | 0 |
| Mean | | .26 | 2.234 | .93 |
| Std. Error of Mean | | .019 | .181 | .052 |
| Std. Deviation | | .810 | 7.579 | 2.235 |
| Variance | | .656 | 57.446 | 4.995 |
| Skewness | | 4.370 | 5.508 | 3.679 |
| Kurtosis | | 23.757 | 40.744 | 17.094 |

characteristic of this table is the high values of kurtosis and considerable skewness exhibited by all three dependent variables. Positive values of kurtosis indicate a pointy and heavy-tailed distribution, while negative values indicate a flat and light-tailed distribution. Positive values of skewness indicate a concentration of scores on the left side of the distribution, and negative scores indicate a similar clustering on the right side. The further the values are from zero, the more likely it is that the data are not normally distributed (Field 2009, p 138). These data patterns can also be observed in the histograms on Figures Two, Three, and Four. The figures provide a depiction of the distribution of scores for the three dependent variables across all samples. The deviation of these distributions from normality is easily assessed when the latter are compared to the ideal normal distribution for these sets of data represented by the thin, curved lines.

SPSS v.19 also provides significance values for the Kolmogorov-Smirnov (K-S) test. The latter is a test of the null hypothesis that there are no significant differences in the distributions between sample and population. All of the comparisons between the dependent variables of mean tooth caries, mean caries/individual, and mean AMTL, and the independent variables represented by Country, Region, Economy, Period, Sex, Status, and Age produced a statistically significant K-S Sig. value of .000. Attempts to transform the data using the logarithmic (Log10) and square root (Sqrt) functions available on SPSS v. 19 did not change either the shape of the distribution, or the respective results of the K-S test.

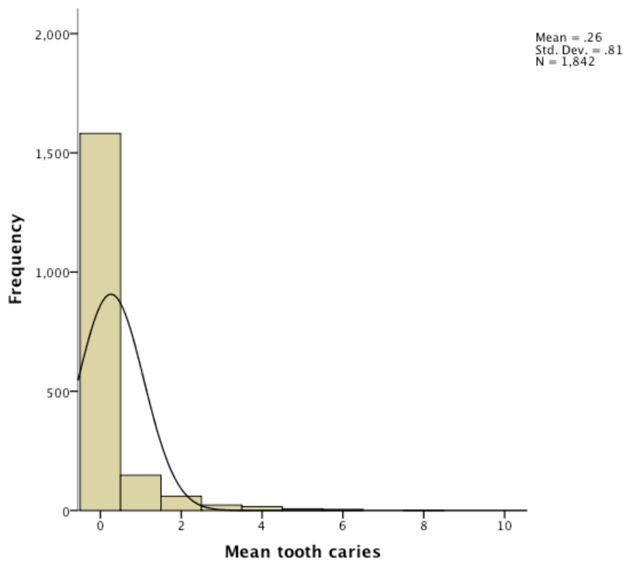


**Figure 2.** Tooth caries histogram. The curved lines here and in Figures Three and Four represent ideal normal distributions for these sets of data.

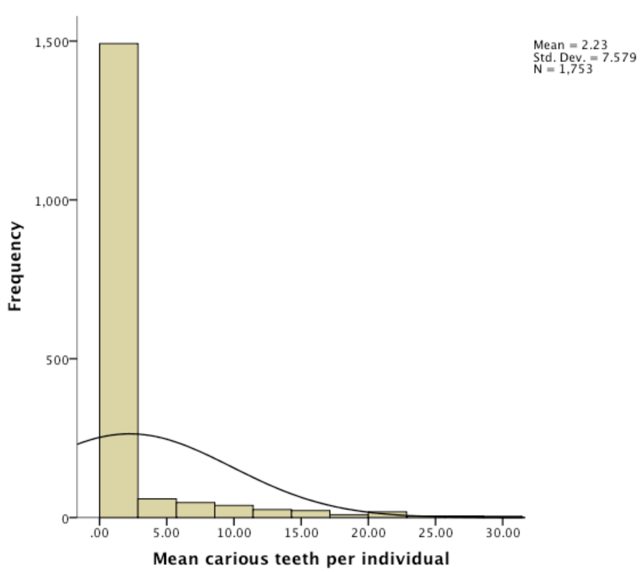


**Figure 3.** Histogram of caries per individual.

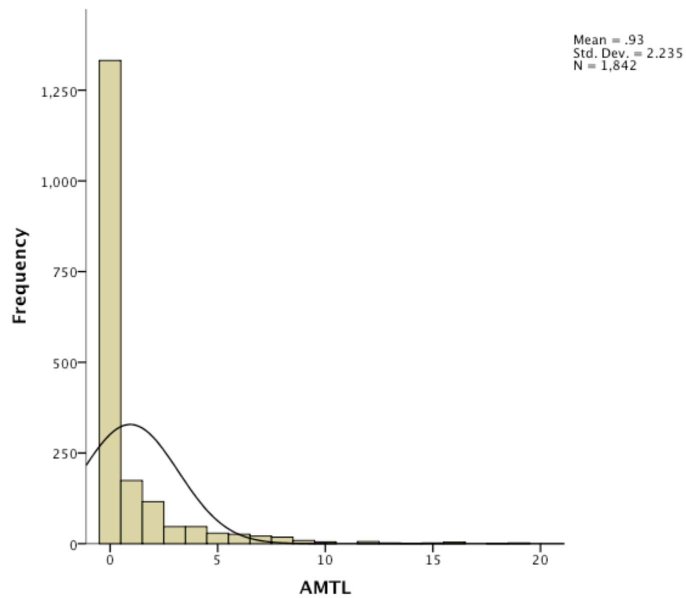


**Figure 4.** Mean AMTL histogram.

Thus it is evident that the data in this study is not normally distributed. However, as was mentioned earlier, violations of normality can be tolerated well in larger size samples. The amount of variability in a sampling distribution (represented by the standard error of the mean) tends to decrease as sample size (n) increases. The latter happens because the standard error of the mean is computed by dividing the standard deviation of the population by the root of n. As the denominator (n) increases, the result of the division gets smaller. Thus increasing sample size reduces the spread of a distribution and increases the probability that a random score will fall within the +/− two standard deviations expected in a normal distribution (Hinton 2004). Parametric statistical techniques, such as ANOVA, can be particularly robust and reliable in situations were normality is violated (Field 2009), and as such violation of normality alone does not constitute adequate reason for use of non-parametric techniques.

However, the three DV in this study are also in violation of another important assumption in parametric statistics, that the populations involved in any study share the same, or similar, variances. Also known as homogeneity of variance, this assumption states that, as one goes through the calculations for the factors in an independent variable, the variance among them should not change (Field 2009). Like normality, homogeneity of variance is greatly affected by sample size, but in different ways. ANOVA remains fairly robust to violations of homogeneity of variance between samples of equal size but unequal size samples that violate the assumption can negate meaningful interpretations of data (Gravetter and Wallnau 2008, p 275). When groups with larger sample sizes have larger variances than smaller-sized groups, the resulting F-ratio tends to be conservative. This means that a significant result may not be detected, even though it represents a genuine difference in the population. Conversely, when the larger sample sizes have smaller variances than the smaller-sized groups, the F-ratio tends to be liberal, i.e. detect significance where there is really none (Field 2009, p 360). Sampling studies regarding *t*-tests indicated that when sample variance were greater than four times another sample variance *and* the samples were of unequal size, one should avoid conducting the test (Howell 1995). SPSS provides means for quick homoscedasticity (as homogeneity of variance is otherwise known) assessment with Levene’s test and statistic. Levene’s test is used to evaluate the assumption that the variances in different groups are equal, or homogenous (Field 2009, p 150). If the variances are not homogenous, it is possible for a null hypothesis (i.e. that there are no differences) to be rejected not because the sample means truly differ from each other but because the sample variances do (Madrigal 1998, p 102). When Levene's value is smaller than .05, the test is significant and the null hypothesis is rejected (Field 2009). In this study, a significant Levene's test value of .000 was produced for *all* comparisons between the three DV and the various factors of the IV, $p < 0.05$. The only exception was Levene's test value for mean caries/indiv. and Economy; the latter however was still significant, albeit with a small margin (Sig. 0.041).

As mentioned already, deviations from homescedasticity are again tolerated well in parametric statistics, granted that samples are composed of equal, or similar, size (Field 2009). In n comparisons that involve unequal size samples, the variance in the larger sample(s) may unduly influence the F statistic in ways similar to those discussed for normality (Field 2009). SPSS automatically provides *t* and F values that have been adjusted to meet violations of homescedasticity, and it is those that are reported in Appendix A. Additionally, SPSS offers a variety of post hoc tests that can be used when parametric assumptions are not met by the data, including situations in which sample sizes are different. Several of them are specifically designed for situations in which population variance is also different, such as Tamhane's T2, Dunnett's T3, and Games-Howell (G-H). Among these, the G-H procedure offers the best performance and is the most powerful in situations where samples of unequal size also violate homoscedasticity (Field 2009, p 374). ). All post hoc tests are designed to compensate for the increased possibility of Type I error, i.e. detecting an effect in a population when there is, in fact, none. The G-H compensates for the latter by adjusting the degrees of freedom to incorporate the differences in sample size and variance of each group being compared (Tabachnick and Fidell 2006). Thus the G-H is considered the most appropriate post hoc test for the parametric comparisosns in this analysis, and significance for all results reported in Appendix A was based on the latter test.

This rather involved discussion about parametric assumptions in this section is used to establish the need for and the reasoning behind the use of non-parametric statistics as primary mean of statistical inference. It is also a useful reminder of the fact that in quantitative analyses sometimes the results are influenced by the method one chooses to use. This must be kept in mind when interpreting the results from both the G-H and the Bonferroni-corrected tests in this analysis. Aside from the search for statistical significance, much useful information exists in the diachronic caries trends that characterized each period. It is under this premise that most of the following discussion in this thesis takes place.

# CHAPTER 6

# RESULTS

This thesis is concerned with caries prevalence in ancient Egyptians and Nubians as an indicator of temporal changes in diet, dental health, and social organization within the specific bio-cultural context of NE Africa. Caries data for this study derived from 26,196 teeth belonging to 1,842 ancient Egyptians and Nubians from 32 cemeteries of mixed sex, age, and status. From these, 484 teeth (1.8%) belonging to 261 individuals (14.2%) had at least one carious lesion. Overall, the most common lesion was of the occlusal type and the most commonly affected teeth were the molars (449 in 484 carious teeth, or 92.8%). From the 449 molars with carious pathology, 298 (66.4%) belonged to the lower jaw. The pattern was reversed for the anterior dentition, with the incisors, canines, and premolars of the upper jaw showing equivalent or higher caries prevalence than those of the lower jaw (Table Six). The severity of the disease is low with 208 of

**Table 6.** Caries per tooth and jaw

| | I1 R | I1 L | I2 R | I2 L | C R | C L | P1 R | P1 L | P2 R | P2 L | M1 R | M1 L | M2 R | M2 L | M3 R | M3 L | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Upper** | 1 | 0 | 1 | 2 | 0 | 1 | 4 | 1 | 3 | 8 | 13 | 19 | 29 | 43 | 28 | 19 | 172 |
| **Lower** | 0 | 0 | 0 | 0 | 1 | 3 | 3 | 0 | 3 | 4 | 23 | 25 | 68 | 66 | 60 | 56 | 312 |

261 carious individuals (79.7%) possesing two or less carious teeth. Ante mortem tooth loss (AMTL) totaled 1720 teeth (Table Seven). When expressed as a rate (AMTL / AMTL + total teeth observed), it produced an overall AMTL prevalence of 6.6 %. The rest of this section is concerned with results for the various comparisons explained in the

Methods Chapter above. Within the various tables that accompany the results, statistically significant differences at .05 level are indicated with an asterisk (*).

**Table 7.** Carious teeth frequencies.

| | | Individuals | Percent |
|---|---|---|---|
| Carious teeth | 0 | 1581 | 85.8 |
| | 1 | 148 | 8.0 |
| | 2 | 60 | 3.3 |
| | 3 | 23 | 1.2 |
| | 4 | 16 | .9 |
| | 5 | 7 | .4 |
| | 6 | 5 | .3 |
| | 8 | 2 | .1 |
| | Total | 1842 | 100.0 |

The ^ symbol is used to indicate significance at the level of the respective Bonferroni corrections for each comparison. Finally, both * and ^, as well as letters of the alphabet, are used to indicate significant differences among samples in some of the parametric tables. For purposes of economy, all parametric results as well as the results from pairwise Mann-Whitney tests are provided in Appendices A and B, respectively.

## Dental caries per Country

The term ‘country’ as applies to this analysis is not meant to denote a nation-state or ethnic affiliation. For lack of a better term, and since Region is already employed to describe a different variable, Country is used for convenience and for the sole purpose of facilitating statistical comparisons between two geographical regions, Egypt and Nubia.

Of all carious teeth, 323 (67%) were Egyptian and the remaining 159 (33%) were Nubian. On an individual basis, 169 (16.6%) of the 1019 Egyptian individuals and 92

**Table 8.** Mann-Whitney results for Country

| | Country | N | Mean Rank | Sum of Ranks | Mann-Whitney U | Asympt. Sig (2-tailed) |
|---|---|---|---|---|---|---|
| Teeth with caries | Egypt | 1016 | 927.58 | 942419.00 | | |
| | Nubia | 825 | 912.90 | 753142.00 | | |
| | Total | 1841 | | | 412417 | .331 |
| Carious teeth per individual | Egypt | 976 | 881.00 | 859855.00 | | |
| | Nubia | 776 | 870.84 | 675773.00 | | |
| | Total | 1752 | | | 374297 | .50 |
| AMTL | Egypt | 1016 | 910.59 | 925162.50 | | |
| | Nubia | 825 | 933.82 | 770398.50 | | |
| | Total | 1841 | | | 408515.5 | .237 |
| * significant at .05 level | | | | | | |
| ^ significant at .008 (Bonferroni) | | | | | | |

(11.8%) of the 734 Nubians included in this comparison suffered from at least one carious lesion. Of those, a majority of 131 (77.5%) Egyptians and 77 (83.6%) Nubians showed a moderate severity of two or less carious teeth.

Neither the Egyptian nor the Nubian populations experienced high rates of AMTL. Egyptians totaled 924 (6.3%) teeth lost antemortem, while the same rate for Nubians was 792, or 6.9%, of teeth. The average AMTL was 0.87 for Egyptians and 1.01 teeth for Nubians. According to results from Mann-Whitney tests, none of these differences is statistically significant (Table Eight). The results of the parametric results for comparisons by Country parallel these in Table Eight, with the exception of mean tooth caries, where the latter was significantly higher among the Egyptian samples. All of the parametric results for Country, including the means and percentages mentioned above, may be observed in Table A1, Appendix A.

## Dental caries per Region

There were statistically significant mean differences for all three dental caries indicators between the various regions involved in this study, i.e. Lower Egypt (LE), Upper Egypt (UE), Lower Nubia (LN), and Upper Nubia (UN). All differences remained significant after Bonferroni correction. The results of the Kruskal-Wallis tests by Region are presented in Table 9 below.

**Table 9.** Kruskal-Wallis results for Region

| | **Region** | **N** | **Mean Rank** | **Chi Square** | **Asympt. Sig.** |
|---|---|---|---|---|---|
| Teeth with caries | Lower Egypt | 312 | 1009.41 | | |
| | Upper Egypt | 752 | 907.40 | | |
| | Lower Nubia | 499 | 871.30 | | |
| | Upper Nubia | 278 | 947.78 | | |
| | Total | 1841 | | 36.630 | .000*^ |
| Carious teeth/indiv | Lower Egypt | 306 | 957.75 | | |
| | Upper Egypt | 712 | 863.60 | | |
| | Lower Nubia | 465 | 828.99 | | |
| | Upper Nubia | 269 | 900.35 | | |
| | Total | 1752 | | 34.030 | .000*^ |
| AMTL | Lower Egypt | 312 | 984.38 | | |
| | Upper Egypt | 752 | 881.82 | | |
| | Lower Nubia | 499 | 927.18 | | |
| | Upper Nubia | 278 | 944.78 | | |
| | Total | 1841 | | 14.724 | .002*^ |
| *significant at .05 level | | | | | |
| ^ significant at .008 level (Bonferroni) | | | | | |

Individual Mann-Whitney tests showed that LE had significantly higher mean ranks for tooth caries, caries per individual, and AMTL than all other regions in the comparison. UE had significantly higher tooth caries and caries per individual than LN. UN had significantly higher mean ranks for AMTL than UE. Finally, LN showed significantly higher tooth and individual caries than UN. Individualized Mann-Whitney tests for all comparisons are presented in Appendix B. The parametric results for Region parallel those on Table 9, especially with regard to LE. Some discrepancies in statistical significance occur between the other regions, but, generally, both parametric and non-parametric statistical results point to similar trends by Region. As with all other results, summary parametric comparisons for Region can be seen in Appendix A.

## Caries per Economy

'Economy' in this thesis is a categorical variable with three sub-samples, Preagricultural, Agricultural, and Intensive Agricultural. The Preagricultural sample is identical to the Prehistoric sample and both belong to the same five Nubian cemeteries that are discussed more extensively in the Materials chapter above. The Agricultural and Intensive Agricultural categories are mixed and included Nubian, Egyptian, as well as later Egypto-Persian, Greco-Egyptian, and Romano-Egyptian cemeteries. The results of the Kruskal-Wallis test for Economy are presented in Table 10 below.

The only statistically significant differences, both at .05 level and with Bonferroni correction (0.005), occur for mean ranks of AMTL. Individualized Mann-Whitney tests indicate that Intensive Agriculturalists experienced significantly higher AMTL than both the preagriculturalist and agriculturalist samples included in the study. The results from these tests are presented in Table B2, Appendix B. These results are in are in overall agreement with the respective parametric tests for Economy. However, the latter also

**Table 10.** Kruskal-Wallis results for Economy

| | Economy | N | Mean Rank | Chi Square | Asympt. Sig. |
|---|---|---|---|---|---|
| Teeth with caries | Preagricultural | 231 | 884.18 | | |
| | Agricultural | 1153 | 926.87 | | |
| | Intense Agricultural | 457 | 924.8 | | |
| | Total | 1841 | | 3.46 | .177 |
| Carious teeth per individual | Preagricultural | 209 | 843.11 | | |
| | Agricultural | 1103 | 882.28 | | |
| | Intense Agricultural | 440 | 877.88 | | |
| | Total | 1752 | | 2.76 | .252 |
| AMTL | Preagricultural | 231 | 874.36 | | |
| | Agricultural | 1153 | 899.1 | | |
| | Intense Agricultural | 457 | 999.84 | | |
| | Total | 1841 | | 22.02 | .000*^ |
| * significant at .05 level | | | | | |
| ^ significant at .005 level (Bonferroni) | | | | | |

detected significant difference in mean tooth caries between Intensive Agriculturalists and Preagriculturalists, but the significance value for that test (0.24) was much higher than the respective Bonferroni correction of 0.005.

## Dental caries per Period

The reasoning for the inclusion of the category ‘Period’ in this study of caries comparisons is explained in the Methods chapter above. ‘Period’ is the categorical variable with the most factors and hence looks at smaller aggregates with the overall population of samples. Inter-sample comparisons in Period may thus better partition any unexplained variance from previous comparisons by Country, Economy, and Region. The results from the Kruskal-Wallis test for Period are provided in Table 11. Statistically significant differences in mean rank were detected for all three dependent variables in

**Table 11.** Kruskal-Wallis results for Period

| | **Period** | **n** | **Mean Rank** | **Chi Square** | **Asympt. Sig.** |
|---|---|---|---|---|---|
| Teeth with caries | Prehistoric | 231 | 884.18 | | |
| | Predynastic | 413 | 896.42 | | |
| | Early Nubian | 162 | 962.27 | | |
| | Dynastic | 346 | 924.3 | | |
| | Classic Nubian | 233 | 931.29 | | |
| | Late Dynastic | 257 | 982.06 | | |
| | Late Nubian | 199 | 884.52 | | |
| | Total | 1841 | | 20.137 | .003* |
| Carious teeth per individual | Prehistoric | 209 | 843.11 | | |
| | Predynastic | 384 | 853.71 | | |
| | Early Nubian | 150 | 925.04 | | |
| | Dynastic | 339 | 876.05 | | |
| | Classic Nubian | 230 | 884.5 | | |
| | Late Dynastic | 253 | 929.04 | | |
| | Late Nubian | 187 | 841.57 | | |
| | Total | 1752 | | 17.59 | .007* |
| AMTL | Prehistoric | 231 | 874.36 | | |
| | Predynastic | 413 | 803.6 | | |
| | Early Nubian | 162 | 828.16 | | |
| | Dynastic | 346 | 981.76 | | |
| | Classic Nubian | 233 | 1008.69 | | |
| | Late Dynastic | 257 | 986.73 | | |
| | Late Nubian | 199 | 1001.18 | | |
| | Total | 1841 | | 74.366 | .000*^ |
| * significant at .05 level | | | | | |
| ^ significant at .002 level (Bonferroni) | | | | | |

the analysis. However, the only significance value that falls below the appropriate Bonferroni correction (.002) was for AMTL. Pairwise Mann-Whitney tests among the various factors in Period also show that the significant values for AMTL are consistently near, or below, the adjusted critical limit of .002. Thus it appears that AMTL results could be viewed with increased confidence, compared to the other two depended variables, at least for the comparisons by Period. A more detailed discussion concerning power in non-parametric statistics, especially in relation to committing Type II error, will be provided in Chapter Seven below. Pairwise Mann-Whitney tests were numerous for Period (21 in total) and again detailed results are provided in Table B3, Appendix B.

Overall, the significant differences in mean ranks for tooth and individual caries among the factors within the category Period tended to separate the chronologically earlier samples (Prehistoric, Predynastic, Early Nubian) from later ones. A spike was also observed in these two variables for the Early Nubian component. This spike was enough to significantly separate Early Nubians from the two earlier samples (Prehistoric, Predynastic), as well as later ones. The Dynastic, Classic Nubian, Late Dynastic, and Late Nubian components had significantly higher mean ranks for AMTL than all three of the earlier samples in the comparison. Thus it appeared that significant AMTL increase in later periods was accompanied by lesser increase in tooth and individual caries. This last implies that there were other reasons involved in higher AMTL in later Egyptians and Nubians than dental caries. A more thorough discussion again takes place in the following chapter.

### Dental caries and Sex

All of the results reported in this section were calculated after the exclusion of the individuals with undetermined sex from the various comparisons. Statistical significance of sex differences in dental caries between samples was assessed using individual Mann-Whitney tests for non-parametric and *t*-tests for parametric comparisons. Tables of these

**Table 12.** Overall sex caries comparisons.

| | Sex | n | Mean Rank | Asympt. Sig. |
|---|---|---|---|---|
| Teeth with caries | Male | 675 | 731.74 | |
| | Female | 794 | 737.77 | |
| | Total | 1469 | | .671 |
| Carious teeth per indiv. | Male | 666 | 717.08 | |
| | Female | 775 | 724.37 | |
| | Total | 1441 | | .607 |
| AMTL | Male | 675 | 753.92 | |
| | Female | 794 | 718.91 | |
| | Total | 1469 | | .054 |
| * significant at .05 level | | | | |
| ^ significant at .01 level (Bonferroni) | | | | |

results are provided in Appendices A and B. Table 12 above shows Kruskall-Wallis test results for dental caries indicators between males and females of the entire sample population. Both non-parametric and parametric tests detected very few statistically significant differences according between males and females. Thus an initial evaluation of results indicated that males and females were affected by dental caries in more or less equal ways. Most of the significant differences occurred in comparisons among the four factors in Region. Upper Nubian females had significantly higher mean ranks for tooth and individual dental caries than their male counterparts. At the same time, Lower

Egyptian males showed significantly higher AMTL than the respective females of their sample. The only significant sex difference that did not involve the variable Region, occured for mean ranked AMTL among males of the Late Dynastic component (the variable Period). This last difference was also the only to be close to, or below, the significant .002 level of the Bonferroni correction, for both parametric and non-parametric tests. As before, concordance was generally observed between parametric and non-parametric results. The only discordance between the two sets of results was significantly higher individual caries for Preagricultural males detected by parametric *t*-test. However, at a p value of .048 and an $Eta^2$ of .0014 (only 1.4% of the difference in means in the dependent variable could be explained by the difference in means the independent variable), this last parametric result may be interpreted with great caution.

**Dental caries and (Social) Status**

All results that entail the independent variable Status (Social Status) must be viewed with caution. The reasons behind such caution are explained in more detail in the Methods chapter above. With the exception of the Upper sub-category, the other two sub-categories in Status (Middle, and Lower) are temporally and geographically constrained to few cemeteries and thus cannot be considered representative of diachronic dental caries trends for the whole of Egypt. However, dental caries results by Status may be prove useful as comparative tools and are thus provided nevertheless. As with all other tables, parametric results and pairwise mann-Whitney tests are provided in Appendix A and B, respectively. The results of the Kruskal-Wallis test for Status indicated that statistically significant differences existed for all dental caries indicators (Table 13).

**Table 13.** Kruskal-Wallis results for Status.

| | **Status** | **n** | **Mean Rank** | **Chi Square** | **Asympt. Sig.** |
|---|---|---|---|---|---|
| Teeth with caries | Lower | 311 | 449.61 | | |
| | Middle | 134 | 440.29 | | |
| | Upper | 491 | 488.16 | | |
| | Total | 936 | | 15.142 | 0.0018^ |
| Carious teeth/individual | Lower | 288 | 431.17 | | |
| | Middle | 132 | 419.91 | | |
| | Upper | 477 | 467.82 | | |
| | Total | 897 | | 14.509 | 0.001*^ |
| AMTL | Lower | 311 | 397.55 | | |
| | Middle | 134 | 471.58 | | |
| | Upper | 491 | 512.6 | | |
| | Total | 936 | | 57.175 | .000*^ |
| * significant at .05 level | | | | | |
| ^ significant at .005 (Bonferroni) | | | | | |

Pairwise Mann-Whitney tests (Appendix B) indicated that Upper Status individuals had significantly higher mean ranks for tooth caries, individual caries, and AMTL than the other two groups. Additionaly, Middle Status individuals experienced significantly higher AMTL than those of Lower Status. These results are in near- complete agreement with parametric comparisons for Status. The latter detected significantly higher AMTL in upper status individuals compared to middle status, which was not the case with the Mann-Whitney test.

Although the results of Social Status comparisons are by the lack of sample representativeness mentioned earlier, other research provides some support for higher rates of dental disease and AMTL in upper class Dynastic Egyptians (Hillson 1979, Forshaw 2009). Future research using more representative samples is necessary in order to arrive to more specific conclusions about the relationship of social status and dental caries in ancient Egypt.

# CHAPTER 7

# DISCUSSION

Many previous investigators have reported on dental disease in Egypt and Nubia (Ruffer 1920, Leigh 1925, Armelagos 1966 and 1969, Leek 1966, 1972a, and 1972b, Koritzer 1968, Greene et al. 1967, Greene 1972, Greene 2006, Grilletto 1973, Hillson 1979, Ibrahim 1987, Beck and Greene 1989, Coppa and Macchiareli 1983, Harris and Ponitz 1983, Smith 1986, Rose et al. 1993, Beckett and Lovell 1994, Crivellaro 2001, Matovich 2002, Pain 2005, Greene 2006, Judd 2008, Forshaw 2009). None, however, had the opportunity to examine dental caries in northeast Africa from such a temporally and numerically broad base, such as that available for this study. This chapter intends to go beyond simplistic descriptions of caries differences to exploring the likely biocultural processes that helped shape them. It is thus hoped that the following discussion will not only provide new insights into the interaction of diet, disease, and cultural change in northeast Africa across time, but will also lead to the posing of questions that will help further research on these subjects.

The avenues for discussion are provided by the research questions posed in the introductory chapter of this work and the results presented in the previous chapter. To avoid repetition, all research questions are addressed simultaneously in relation to three main thematic sections. The first addresses aspects of variability in dental caries and AMTL between Egypt and Nubia. The second section considers variability in caries and AMTL prevalence within Egypt and Nubia, while the third provides a summary of the findings applicable to each research question posed in the introductory chapter of this thesis.

The discussion in this chapter focuses primarily on an evaluation of results obtained from the non-parametric comparisons. The latter, as has been mentioned before, consisted of Kruskal-Wallis and Mann-Whitney tests for evaluation of post hoc relationships. Parametric tests consisted of *t*-tests and independent-measures ANOVA; the Games-Howell test was used for evaluation of post hoc relationships. Results from the latter are also discussed, albeit to a lesser extend, and only to provide additional information for dental caries patterns discernible in non-parametric conclusions. Use of both parametric and non-parametric techniques may appear time consuming but contrasting the results of both sets can be useful tool for statistical inference in studies of similar scope and content as this one. As it turned out, both sets of results are highly concordant. The implications of this fact are discussed throughout the remaining body of the thesis.

## Egypt and Nubia

Overall, Egypt had higher tooth and individual caries frequencies than Nubia, but slightly less AMTL. However none of these differences were statistically significant, either at .05 or .008 (Bonferroni correction). One of the most immediately apparent findings in this study is that overall tooth caries rates increased through time in both regions. Concurrently, dental caries prevalence remained low in Egypt and Nubia when compared to caries prevalence in other agricultural populations. From the total number of teeth examined for the two sub-populations, only 2% of Egyptian and 1.4% of Nubian teeth suffered at least one carious lesion. Individual caries percentages were higher at 16.6% and 11.8% for Egyptians and Nubians, respectively. Although individual caries rates were still moderate, they were higher than tooth caries. These figures (Appendix A) may be an indication that the overall low tooth caries prevalence affected some segments of the population disproportionately.

In any case, Egyptian and Nubian tooth caries rates were certainly much lower than the 8.8% tooth caries rates in worldwide pre-industrial agriculturalists reported by Turner II (1979). It is also significant that in their study of maize agriculture in the Lower Mississipi Valley, Rose and co-workers (1985) considered a mean caries per individual below 2.0 to indicate non-agricultural populations. Besides low prevalence, the ancient Egyptians and Nubians in this study also enjoyed low levels of caries severity, for 131 of 169 carious Egyptians (77.5%) and 77 of 92 carious Nubians (83.7%) had two, or less, carious teeth (Appendix A). AMTL frequencies were also kept at a moderate level in Egypt and Nubia, considering the levels observed among other preagricultural and agricultural populations. At the same time, absolute AMTL frequencies in both Egypt and Nubia exceeded those for tooth caries by almost three to one. This relationship suggests that there were factors other than caries involved in AMTL. Dental pathology in the two country-level samples in this study may be more complicated than initially indicated by the (very) low caries frequencies. This fact will become more evident in the discussion that follows below.

AMTL, individual, and tooth caries frequencies appear to have been experienced equally among males and females in Egypt and Nubia. Dental caries comparisons between the two countries by sex did not yield any statistically significant differences. Egyptian and Nubian females posses equivalent or higher caries prevalence than their respective males for all three caries indicators. The only exception was the higher individual caries prevalence in Nubian males. Perhaps it is of interest to note that over half of Nubian carious teeth belonged to females. Although this difference is not significant, it appears from the data that Nubian females were affected by dental caries in a more uneven fashion than Egyptian females.

**Egypt**

So far, the resultsof the current study have been in general agreement with previous caries research in Egypt. Ibrahim (1987) reported 3.3% carious teeth in the 21-30 year old group and 3.5% in the 31-40 year old group in Predynastic through Late Dynastic Egyptian skulls. Greene (2006) found a very low 6% tooth caries rate for Predynastic teeth from Hierankopolis, while Pain (2005) reported that 16% of individuals from the same period possessed carious teeth. Finally, Brothwell (1963) examined 1732 Late Dynastic teeth (Dynasties 26-30) and found only 2.06% of them to be carious.

Ancient Egyptians, from the late Predynastic onwards, were intensive agriculturalists who practiced complex, irrigation-based land management and relied upon cereal-derived staples of bread and beer for most of their daily dietary needs (e.g. Clark 1971, Grilletto 1973, Butzer 1976, Hoffman et al. 1986, Hassan 1984, 1988, Bard 1994, Fahmy 2000, Samuel 2000). Although there are exemptions (Turner II 1978, Chamberlain and Whitkin 2003, Adler and Turner II 2000, Schollmeyer and Turner II 2004), worldwide population caries frequencies comparisons have identified a close association between an increase in caries rates, the adoption of agricultural techniques, and a greater reliance on soft, carbohydrate-rich cereals and grains (Turner II 1979, Walker and Hewlett 1990, Lukacs 1992, Larsen 1997, 2006). Among cereals, rice appears to have some cariostatic effect (Screebny 1983, Tayles et al. 2000). Thus one would expect higher caries frequencies in a population with a primary dependence on wheat, barley, and sorghum, as was the case among the ancient Egyptians. This apparent contradiction can be explained if Egyptian dental caries rates are seen in the light of the relationship between dental caries and other plaque-induced oral pathologies, especially attritional wear and periodontal disease.

## The relationship between dental caries and dental wear

Although the subject of dental wear is too broad to be covered extensively here, some mention must be made of dental wear because of the functional interrelationship that exists between caries levels and grades of wear on teeth. In short, tooth wear is a natural biological process and there are very few, if any, archaeological or modern human populations that are entirely free from dental wear (Hillson 2000). The effects of wear on the structure, function, and morphology of teeth are the result of the combined action of attrition and abrasion. Attrition is normal wear caused by tooth-on tooth contact during mastication. Abrasion is abnormal, non-masticatory wear caused by interference of foreign bodies between the occlusal surfaces of teeth (Leek 1972a, Molnar et al. 1972, Scott and Turner 1988, Scott 1991). Wear patterns of attrition and abrasion on teeth are very useful in the archaeological record for distinguishing hunter-gatherer-fishers from agriculturalist populations. Generally speaking, the former display more homogenous and flat wear over the entire dentition, with pronounced wear of the anterior teeth. Agriculturalists on the other hand generally show a greater degree of abrasive, cupped wear concentrated on the posterior teeth (Leigh 1925, Molnar et al. 1972, Smith 1984b, Hinton 1982).

The importance of considering tooth wear when analyzing caries rates arises from the fact that the amount and rate of dental wear in a population can directly affect the prevalence and severity of dental pathologies, including caries (Powell 1985). Constant, moderate amounts of wear can act as oral prophylactic during one's lifetime by removing occlusal bumps and fissures that are prime loci for dental caries proliferation. On the other hand, wear that exceeds the rate of deposition for secondary dentine can expose the latter, and ultimately the pulp, to cariogenic bacteria (Powell 1985). Further, excessive amounts of wear can also lead to tooth chipping and/or loosening of the tooth in its socket, which can provide cause for development of periodontal disease and root caries. Finally, continuous tooth eruption, which acts as a compensatory mechanism for tooth height lost to wear, can rapidly expose the interproximal and root surfaces of teeth to infectious plaque bacteria (Caglar et al. 2007, Hillson 2008).

The played by dental wear in ancient Egyptian caries rates was considerable, judging from the high, and sometimes extreme, levels of wear encountered on Predynastic and Dynastic teeth. Very early in the dental anthropology of ancient Egypt

Leek (1966) noted that the chief pathology of Dynastic dentitions was not caries but extreme patterns of attritional wear. The latter was more pronounced on the maxillary molars that, in many cases, had exposed dental pulps and associated periapical abscesses (Leek 1966). Overall, the combined effects of wear and plaque accumulation created a dental profile that for most of the Dynastic period was characterized by various degrees in the occurrence of chipping, fractures, alveolar bone resorption, periodontal disease, accumulation of calculus, periapical abscessing, and early loss of teeth during life (Saffirio 1972, Hillson 1979, Smith 1986, Pain 2005). These pathologies could provide cause for chronic infections of the bone, chronic, low-intensity systemic stress, blood poisoning, and even death. Based on the lack of archaeological or textual evidence for any systematic oral hygiene practices (Hillson 1979), we can assert that many, if not most, Dynastic Egyptians would have been faced with serious dental problems at some point in their adult life. That this dental reality extended to members of the elite was revealed by the abhorrent dental state seen on the mummy of one of Egypt's greatest pharaohs, Amenhotep III (1390-1352 BCE). His dentition constituted a dentist's nightmare, and came complete with extreme attritional wear and exposure of the pulp, fractures and chipping, AMTL, root caries, severe cavitation, and loss of alveolar bone (Pain 2005).

The primary reason for such a painful dental state among the ancient Egyptians must be sought in culturally mediated ways in the preparation of food, and especially that of bread. Predynastic and Dynastic Egyptian diet was remarkably diverse and included vegetables, occasional servings of animal meat, milk and cheese, fruit, fish, poultry, and fowl (Crawford 1979, Van Neer and Linseele 2002). Additionally, ancient Egyptians used plant fats as condiments, made use of oils derived from sesame and safflower seeds, and husbanded bees from which they derived honey (Morcos and Morcos 1977, Greene 2006). Most people shared a primarily vegetarian diet while members of the elite, such as kings, officials, and priests may have consumed more meat protein, primarily from cattle (Saffirio 1972, Matovich 2002, Pain 2005, Greene 2006).

However, for the overwhelming majority of ancient Egyptians their daily dietary staples came in the form of bread and beer. Bread was derived from emmer wheat and barley and was so important that it was rationed to public officials on foreign missions, workers, and soldiers on assignments (Leek 1972b, Geller 1992). The plentiful archaeological, textual, and pictorial evidence in existence testifies to the fact that flour preparation techniques and storage practices introduced highly abrasive foreign material into Egyptian bread. For example, pictorial representations of milling scenes in Egyptian art show use of limestone querns that undoubtedly would have caused abrasive material from the stones to mix with flour during grinding. It is also possible that ancient Egyptians may have added grit willingly so it could act as a cutting agent during the milling process (Leek 1972b, Smith 1986).

In any case, a microscopic analysis of Dynastic teeth by Puech and coworkers (1983) showed that microwear patterns on molars were consisted with particles of dust and wind-blown sand, while radiological and stereoscopical analysis of fossilized Egyptian bread confirmed high consistency of non-organic materials such as quartz, greywacke, and feldspar (Leek 1972b, Smith 1986). Additionally, analysis of the gut content in naturally mummified Predynastic individuals from Hierankopolis revealed that many of the plant remains consisted of husk fragments from emmer wheat and barley. This find suggested that little attempt was made to remove the husks before grinding, and that the bread for the living Egyptians would have been quite coarse and chaff-filled (Fahmy 2000). This bias towards de-husking may have been introduced by the use of coarse sieves (i.e. ones that allowed more material to pass through) during the winnowing process (Morcos and Morcos 1977).

From the perspective of attrition and abrasion, it thus emerges that ancient Egyptians had similar dental wear patterns with other agricultural and preagricultural groups from the greater eastern Mediterranean basin whose dietary practices allowed contamination of foodstuffs with gritty, non-organic substances (Angel 1944, Smith et al. 1984, Papathanasiou 2001, 2005, Eshed et al. 2006). Thus, the unusually low caries rates in ancient Egyptians could be explained by the palliative combined effects of dental attrition and abrasion acting as cleansers by removing the prime caries loci, the fissure system in molars (Ruffer 1920). Some support for this assertion is provided in Ibrahim's (1987) finding that occlusal caries in Dynastic Egyptians was inversely related to dental attrition, with only 5.9% of molars scored as five or more for attrition being carious. However when dental attrition and overall caries levels were cross tabulated, caries were found as commonly on teeth with caries as on those without (Ibrahim 1987). However, Koritzer (1968) analyzed a different sample of Dynastic skulls from Lisht in Lower Egypt and noted that most carious cavities were found on unworn surfaces of molars with deep pits and fissures (p 552). It must also be clear from the discussion thus far that the precise patterns of both micro- and macrowear on teeth are liable to a number of culturally-specific factors that cannot always be accounted for in an archaeological context. Thus both attritional and abrasional wear must be examined on local, sample-specific level, in conjunction with dental caries frequencies for the same population.

An alternative explanation for the low prevalence of dental caries is ingestion of naturally-occuring tetracycline in Egyptian and Nubian bread and beer. Tetracyclines are natural antibiotics produced by mold-like soil bacteria of the genus *Streptomycytes*. Unlike most other bacteria, the latter tend to thrive in dry, alkaline environments and are thus presented with a reproductive advantage in the desiccated conditions of the Egyptian and Nubian landscapes (Armelagos et al. 2001). Tetracyclines are natural chelators of metal ions and form compounds with calciums and proteins as they are deposited in bone (Nelson et al. 2010). Mass-sprectometry of human bone has revealed that absorption of tetracyclines produced a characteristic fluorescent staining in bones that is detectable under ultraviolet lighting (Armelagos et al. 2001, Nelson et al. 2010).

Such characteristic staining was observed on bones recovered from an X-Group (350-550 CE) cemetery in Nubia (Bassett et al. 1980, Armelagos et al. 1981), Christian-era inhabitants (550-1450 CE) of Kolubnarti also in Lower Nubia (Hummert and Van Gerven 1982), and a late Roman-early Byzantine cemetery in the Dakleh Oasis of Egypt (Cook et al. 1989). Proliferation of tetracycline-producing bacteria would have been facilitated by food storage and preparation practices of ancient Egyptians and Nubians. Storing of grains in mud bins would have promoted souring of the bottom-most layers (Bassett et al. 1980, Hummert and Van Gerven 1982), while the bread used in the brewing of beer was partially uncooked and left out in order to capture air-borne yeast (Armelagos et al. 2001).

Ingestion of tetracycline in small amounts and over a prolonged period of time could have dental caries-arresting effects, especially since tetracyclines have broad spectrum antibiotic qualities and are effective against both gram-positive and gram-negative bacteria, which are the majority of bacteria that inhabit the mammalian mouth (Bassett et al. 1980). A possible therapeutic and preventive role of tetracycline was suggested by lack of bone infections (periostitis) in the Dakleh individuals (Cook et al. 1989) and decreased loss of bone mineral content in older females from the X-Group sample (Armelagos et al. 2001). However the potential effect of tetracycline ingestion on prevalence of dental caries remains uncertain and more research is necessary.

If the advanced attrition of ancient Egyptian teeth did play a role in keeping caries rates low, it also likely impacted an array of other plaque-induced pathologies (AMTL, periodontal disease, calculus, jaw bone loss, periapical abscessing) and contributed to a low level of overall dental health. It seems that ancient Egyptians did not make a connection between what they ate and their poor oral health or that if they did, they did not provide any amends. It is possible that, pain and suffering from bad teeth notwithstanding, the tooth was not considered important as an element of the human body. New Kingdom Egyptians viewed the human body as a complex composite of different parts, each of which was essential for individual existence and the journey through afterlife (Meskell 2000). For that reason they took pains to preserve the intact state of the body after death, even with the use of prosthetics, for mummies have been found with artificial toes and fingers. However no false teeth have ever been found (Pain 2005).

**Regional and temporal dental caries comparisons in Egypt**

Besides low overall rates, another characteristic of Egyptian caries was the steady increase in caries rates over time. As can be seen in Table 11, mean ranks for tooth caries and mean ranks for caries per individual increased from the Predynastic to the Dynastic, and then heightened greatly in the Late Dynastic. Both parametric and non-parametric post hoc evauations (using the Games-Howell and Mann-Whitney tests, respectively) indicated that statistically significant differences for all three dependent variables exist between the Late Dynastic and the earliest two periods, Predynastic and Prehistoric. These results are in overall agreement with previous research findings for increasing caries over time in both Egypt (Ruffer 1920, Grilletto 1973) and Nubia (Armelagos 1966, Greene 1972) from Predynastic to Christian times. Increasing caries rates in Egypt are consistent with dietary changes that occured as Egyptian diet shifted from a greater protein intake during the Preagricultural and Predynastic periods to increasing dependence upon carbohydrates from C3 cultigens, such as barley and emmer wheat (Iacumin et al. 1998). Carbon and nitrogen isotopic values extracted from bone collagen of different Dynastic samples showed that this carbohydrate dependency did not change for most of the Dynastic period (Iacumin et al. 1996, White et al. 1999). This of course does not exclude marked regional dietary idiosyncrasies. The latter played important role in the distribution of Egypto-Nubian caries patterns over time and the implications are discussed below.

A clarification is necessary at this point. The Late Dynastic sample here extends over a period that is different from the actual cultural period in Egyptian history. From a cultural-historical perspective, the Late Dynastic begins with the 26th Dynasty at 664 BCE and ends with the first Hellenistic king, Alexander the Great, at 332 BCE (Shaw 2000). In this study, the Late Dynastic component includes mostly Ptolemaic, Roman, and early Byzantine samples; it is best thought of as representing post-Dynastic populations during the later stages of ancient Egyptian history. No matter how the 'Late' category is defined it is an important component of the overall sample because the most significant dietary changes in Egyptian history took place during the Ptolemaic and Roman periods.

The Ptolemaic kings of ancient Egypt undertook a program of complex canalization, irrigation, and land reclamation that culminated in a trebling of the cultivable land around the Fayum up to 1,300 sq km. This figure is similar to that of 1882 CE and comparable to about 1,800 sq km today (Butzer 1976). The Greeks also introduced a litany of new cash crops into Egypt such as castor oil, gourds, safflower, linseed, garlic, and chick-peas. However, the change that must have undoubtedly affected the largest portion of the population was the substitution of the traditional Egyptian staple, husked tetraploid emmer wheat (*Triticum dicoccum*), with a new naked tetraploid variety, *Triticum durum*. The latter was used to produce a finer, white variety of flour known as *semidalis* (Crawford 1979, Foreshaw 2009). In combination with use of traditional Egyptian sweeteners in the form of dates and figs in the baking of bread (Morcos and Morcos 1977), the new flour may have contributed to a stickier substance than the previously coarser Egyptian bread (Pain 2005, Forshaw 2009). When eaten, such bread would tend to stick longer to teeth and promote tooth demineralization for longer periods of time. Most notable among the other cereal strains introduced into Egypt under the Ptolemies was the ‘three-month’ wheat, most likely einkorn (Crawford 1979).

It would be reasonable to assert that these successful Ptolemaic attempts of agricultural intensification would have lead to greater production, and thus consumption, of carbohydrates. This, in turn, is likely to have caused the increased caries rates observed during this period. Another important dietary innovation was the introduction of sugar into late ancient Egypt during Roman times, ca. 100 CE. The Romans also made wider use of honey, and in ways that were different than previously. The Roman practice of weaning infants on goat’s milk together with honey encouraged botulism-related infections and may have contributed to the high prevalence of iron and folic acid anemia-related incidents among Romano-Christian individuals recovered from the Dakhla Oasis (Fairgrieve and Molto 2000, Dupras et al. 2001). Of course even prior to the Roman occupation, ancient Egyptians suffered a variety of congenital and acquired diseases, most of which developed as a result of cultural practices related to diet and water use (David 1985, Sullivan 1995, Vyhnanek et al. 1999).

Aside from agricultural innovations, the Greeks also provided the human vector for leprosy to enter Egypt via India, while other prevalent afflictions observed on Egyptian mummies were tuberculosis, arthritis, osteomyelitis, traumatic lesions from fractures, and non-specific periostotic incidents (Satinoff 1972, Sullivan 1995). Agricultural, soil, and water-use practices in ancient Egypt (as well as in modern) also encouraged prevalence of various parasitic infestations, such as schistosomiasis (*S. haematobium*), head lice, and intestinal worms of the genus *Strongyloides* (David 1985, Kloos and David 2002). These multiple, chronic stresses can lower overall resistance of the immune system to bacteria and thus be conducive to higher caries in later Egyptians. This is however speculation and no such connection can be established in this analysis.

Coincidentally, five of the six Late Dynastic samples (HES, KHA, GEG, HAW) belong to the Intensive Agriculturalist component of the Economy variable in this study. The latter also includes the four Nubian samples KUS, MER, XGR, and CHR. This sub-category is meant to represent intensive agriculturalists in the lower and central Nile Valley ca. 600 BCE-1500 CE. Together with Period, Economy was conceived as a variable to better represent diachronic changes in caries frequencies. Similar to Period, increased tooth caries rates from the Preagricultural to Intensely Agricultural, and statistically significant differences in AMTL exist between the two economies. Individual caries frequencies increased from the Preagricultural to the Agricultural and then dropped slightly in the Intensely Agricultural group, though none of these changes occurred at a significant level. The disproportionate increase in tooth caries compared to individual caries could be an indicator that, though disease rates increased overall, they affected the population in a more or less balanced way. As far as sex differences in dental caries are concerned, previous research indicated non-significant differences for ancient Egyptians (Ibrahim 1987, Greene 2006). In overall agreement with those results, very few sex differences were detected for the caries indicators in this study. Specifically significant differences existed for tooth and individual caries between the males and females of the Upper Egyptian component, while Late Dynastic females had significantly higher AMTL than males.

Besides temporal variation according to period and economy, caries frequencies in Egypt (and Nubia) also showed considerable regional variability. Inferences to the latter in this analysis are mostly based on caries comparisons among the four sub-categories of the categorical variable Region. As described in the Methods chapter above, these regions include Lower Egypt, Upper Egypt, Lower Nubia, and Upper Nubia. As can be seen in Table Nine, statistically significant differences occur for all three of the dental caries indicators among the four regions in the study. Table B1 shows results of the individual Mann-Whitney tests among the latter. There it can be seen that significant differences existed between Upper and Lower Egypt, as well as between Upper and Lower Nubia. Lower Egypt, in particular, had at least one significant difference with all other regions in the group (Table B1). In comparisons with Upper Egypt, Lower Egypt had significantly higher mean ranks for all three dental caries indicators.

This sharp regional contrast may be partially explained by sample composition. The sub-category Lower Egypt is composed of Dynastic and Late Dynastic cemeteries, i.e. the period that showed significant mean tooth caries differences in earlier comparisons. Three of the seven cemeteries from Lower Egypt also belonged to the Late Agriculturalist component in Economy; the latter also showed significant tooth caries difference with earlier economies. These facts about the data raise concern with regards to sample bias. Could the higher content of Lower Egypt in later, intensely agricultural samples be 'weighting' dental caries results in their favor? A closer look into dental caries per individual cemetery is required to explore this possibility. Histograms of mean tooth and individual dental caries per cemetery are illustrated  in Figures Five and Six.

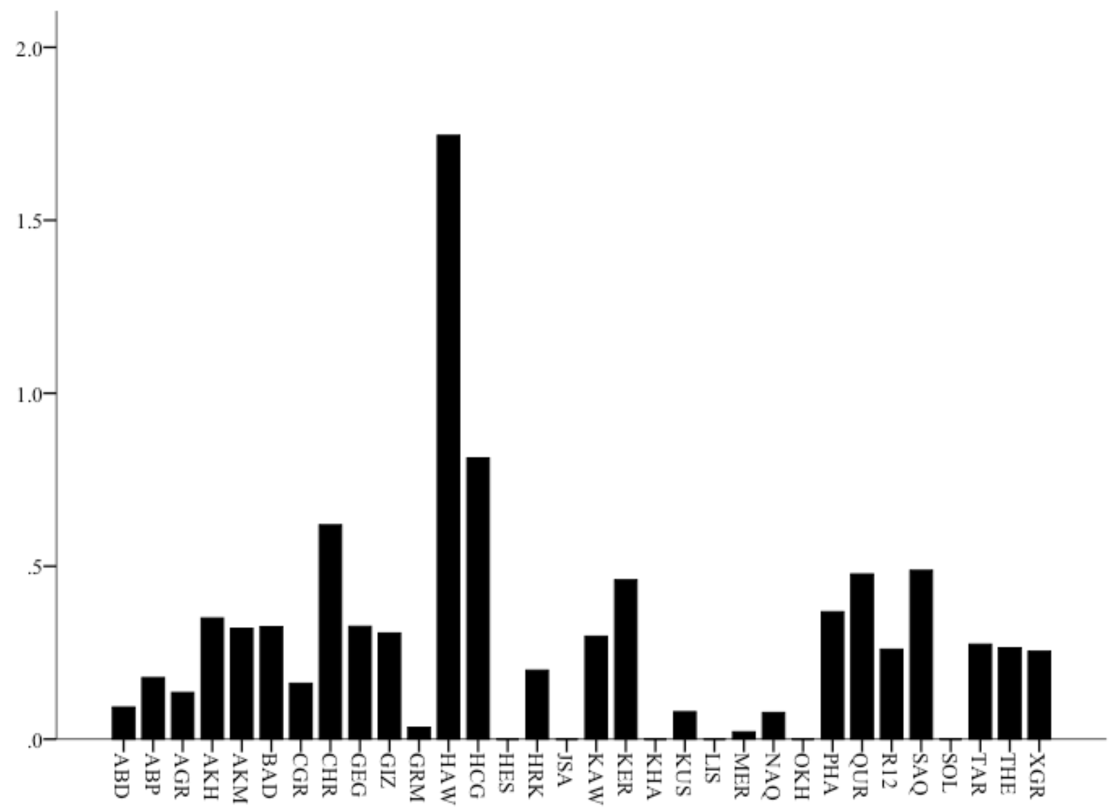


**Figure 5.** Mean tooth caries per cemetery

The most striking elements in the graphs are the relatively high mean tooth and individual dental caries for Hawara (HAW), and to a lesser extend HCG as well. Obviously, HAW had unusually high dental caries frequencies, even at the relative level of this comparison. The question is why? Evidence for higher incidence of dental disease in Roman-period

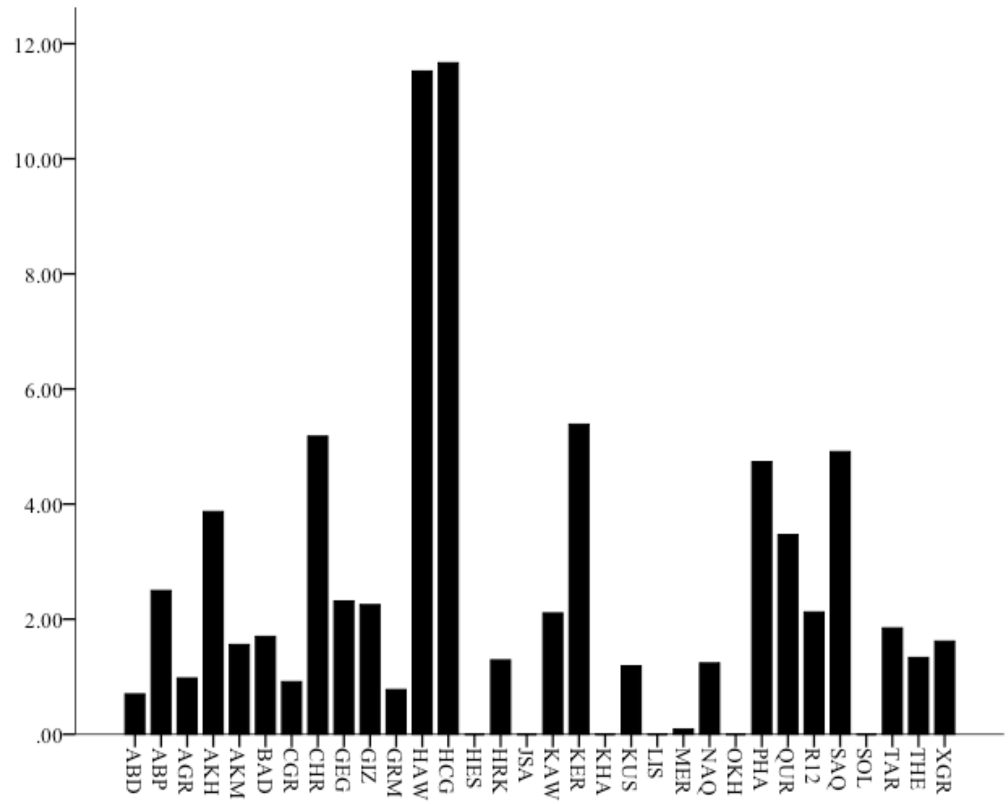


**Figure 6.** Mean individual caries per cemetery

individuals from HAW is also provided by Hillson (1979), who examined 91 individuals and concluded that they had higher incidences of caries, thickness of plaque deposits, and AMTL rates than other cemeteries in the study. Hillson (1979) attributed these pathologies to higher consumption of sugar at HAW, as well as the high prevalence (40%) of linear enamel hypoplasia. The latter take the shape of pit and/or furrow defects in the enamel surface of the tooth (Hillson and Bond 1997) and are caused by disruptions in the activity of ameloblasts during the process of enamel formation. These disruptions can be a result of genetics, trauma, or systemic metabolic stress.

This last is most often associated with episodes of malnutrition or endemic disease during childhood (Ibrahim 1987). Enamel hypoplastic defects can be closely correlated with tooth age-formative processes and their occurrence in sub-adults and infants can indicate febrile disease in agricultural populations related to weaning of infants onto carbohydrate-rich, but nutritionally deficient, agricultural staples (El-Najjar et al. 1978, Hillson 1979, 1996, 2000, Goodman et al. 1984, Goodman and Rose 1990). High prevalence of hypoplasias at Hawara may have played part in the high incidence of caries, since hypoplastic defects provide flaws and weaken the structure of the enamel (Hillson 1979). It is possible that the unusually high caries rates observed in HAW could be related to the synergistic effects of increased sugar consumption together with systemic stress during early childhood. It could also be possible that the cause for increased carbohydrate intake for these people could lay with ethnic, social, or religious identity. In any event, how do results from dental caries comparisons change if HAW is removed from consideration? Tables 14 and 15 show results from Mann-Whitney tests

**Table 14.** Results for Region without HAW.

| **Region** | | **Tooth caries** | | **Individual caries** | | **AMTL** | |
|---|---|---|---|---|---|---|---|
| | n | Mean rank | Asympt. Sig. | Mean rank | Asympt. Sig. | Mean rank | Asympt. Sig. |
| Lower Egypt | 261 | 520.29 | .145 | 496.28 | .197 | 537.35 | 0.011* |
| Upper Egypt | 752 | 502.28 | | 480.26 | | 496.47 | |
| | | | | | | | |
| Lower Egypt | 261 | 399.42 | .002 | 377..87 | .004 | 388.39 | .370 |
| Lower Nubia | 499 | 370.61 | | 351.72 | | 376.37 | |
| | | | | | | | |
| Lower Egypt | 261 | 268.87 | .803 | 261.87 | .801 | 272.26 | .689 |
| Upper Nubia | 278 | 271.06 | | 264.07 | | 267.87 | |

**Table 15.** Results for Period without HAW.

| Period | | Tooth caries | | Individual caries | | AMTL | |
|---|---|---|---|---|---|---|---|
| | n | Mean rank | Asympt. Sig. | Mean rank | Asympt. Sig. | Mean rank | Asympt. Sig. |
| Late Dynastic | 206 | 219.45 | .895 | 206.07 | .895 | 228.94 | .470 |
| Prehistoric | 231 | 218.6 | | 206.92 | | 210.14 | |
| | | | | | | | |
| Late Dynastic | 206 | 308.06 | .728 | 290.86 | .563 | 344.09 | .000* |
| Predynastic | 413 | 310.97 | | 295.66 | | 293 | |
| | | | | | | | |
| Late Dynastic | 206 | 269.58 | .181 | 264.33 | .165 | 270.65 | .425 |
| Dynastic | 206 | 280.62 | | 275.79 | | 279.99 | |
| | | | | | | | |
| Late Dynastic | 206 | 177.94 | .027* | 169.7 | .011* | 195.58 | .003* |
| Early Nubian | 162 | 192.85 | | 186.88 | | 170.4 | |
| | | | | | | | |
| Late Dynastic | 206 | 202.57 | .890 | 195.67 | | 208.69 | .251 |
| Classic Nubian | 199 | 203.42 | | 195.35 | .959 | 197.5 | |

for Lower Egypt (Region) and Late Dynastic (Period) when HAW is excluded from the comparisons. Several important differences become apparent when these tables are compared to Tables B1 and B3. In regional comparisons, exclusion of HAW eliminated three of the six previously significant differences between Lower Egypt and the other three regions. No significant differences remained between Lower and Upper Egypt, in particular. In a similar manner, from the nine previous significant results between the Late Dynastic and the rest of groups in Period only two remained after HAW was removed. Importantly, the only significant difference that remained with the earlier two periods (Preagricultural, Predynastic) was higher AMTL prevalence for the Late Dynastic sample compared to that found for the Predynastic samples. Exclusion of HAW also lead to significant differences for the Late Dynastic where they didn't exist before. The latter's mean ranks for tooth and individual caries were reduced enough so that they were surpassed at a significant level by the Early Nubian sub-group. Hence elimination of HAW raises the possibility that there was an actual reduction in Late Dynastic dental caries rates compared to the earlier (and less agriculturally intensified) Dynastic and Early Nubian periods. Generally speaking, AMTL mean ranks did not change as much as those for tooth and individual caries after the exclusion of HAW. It was actually significant results in AMTL that persisted more through both sets of comparisons. This finding indicates that, HAW notwithstanding, there was a deterioration of overall dental health during the later phases of Egyptian history, but the causes for this deterioration were not related to caries (since caries rates decline without HAW) and must be sought in other plaque-related disease agents, such as periodontal disease, pulp exposure, and abscessing.

Although possible explanations for the high caries rates at HAW have already been discussed, a better understanding of caries patterns at Hawara can be provided by future comparisons between the individuals from the site and other contemporaneous samples from Lower Egypt and the Delta. For the purposes of this study HAW is best considered part of the biocultural continuum that framed dental disease at the time and given the evidence for pronounced regional and individual caries variability in ancient Egypt it is best to retain the sample in the comparisons.

Evidence for ‘true’ caries differences between Upper and Lower Egypt has been provided by other researchers. In his paradigmatic dissertation on ancient Egyptian dental pathology, Ibrahim (1987) found statistically significant differences in both tooth and individual caries frequencies between Lower and Middle Egyptian cemeteries. Moreover, the percentages for carious teeth and individuals given by the author (Ibrahim 1987, p 262) approximate those for Upper and Lower Egypt in this study. Ibrahim's (1987) 'Middle' Egyptian cemeteries were all situated south of Badari and thus, for the purposes of this study, are considered Upper Egyptian. Therefore his results more or less agree with the results of regional caries analysis in this thesis. Ibrahim (1987) also does a convincing job putting forth several explanations for the observed dietary differences between Upper and Lower Egypt. According to him, it is reasonable to assume that the cultural and environmental contrasts between the two regions would have affected both the dietary resources available and the food preparation techniques. For example, the drier and sandier nature of Upper Egypt could have contributed to greater protection against caries through the cleansing effects of attritional wear of tooth surfaces. Alternatively, Upper Egyptians may have consumed more meat than their Lower Egyptian counterparts. Finally, whatever was the cause of sugary consumption in the Egyptian north, it did not subsist in the south: sugar consumption in Upper Egypt was less than that in Lower Egypt (Ibrahim 1987).

It is unclear whether the considerable disparity in AMTL, tooth, and individual caries frequencies between Upper and Lower Egypt (Table Six) is related to the equally important differences in caries sex dimorphism between the two regions. As can be seen on Table A6, Upper Egyptian females have significantly higher tooth and individual caries prevalence than males. Moreover caries sex dimorphism patterns in Upper Egypt were the opposite of those in Lower Egypt, where males held a clear but statistically insignificant lead (Table 10). Removal of HAW from comparisons did not change this relationship between sexes in Lower Egypt. Considering the fact that Upper Egypt also showed some of the lowest tooth as well as individual caries rates, it is evident that the overall low caries prevalence in Upper Egypt affected females in a decidedly disproportionate way compared to their male counterparts.

## AMTL in Egypt

As discussed in Chapter Three, AMTL is a useful indicator of dental disease in a population. This is largely due to the fact that AMTL is a result of pulp exposure from caries, periodontal disease, or excessive wear (Lukacs 1989, Kelley et al. 1991). As with dental caries, a steady increase in AMTL frequencies was observed through time in the present series. This was true for both Egypt and Nubia. Significantly higher AMTL rates compared to all the other groups in the respective comparisons were observed for the Lower Egypt, Late Dynastic, and Intensive Agricultural samples (Table B3).

Statistically significant AMTL increase in the late periods of Egyptian history compared to the Predynastic was also found by Ibrahim (1987), though his figures for AMTL frequencies were much different from the results of this analysis. In light of the previous discussion, it is interesting that AMTL prevalence declined slightly from the Dynastic to the Late Dynastic, with the latter experiencing the lowest AMTL in all agricultural groups from the Dynastic onward. It thus appears that caries and AMTL are inversely related in the Late Dynastic sample although the magnitude of this relationship cannot be ascertained in this study. Some inferences may be drawn by some recent dental and skeletal research in Greco-Roman Egypt. Austin (2013) measured mandibular dimensions and dental wear levels in individuals from the Ptolemaic-Roman site of Karanis (300 BCE-600 CE) in the Fayum region and concluded that during the latter phase a dietary shift occurred from consumption of gritty bread to porridge. The shift was evidenced by the decreased levels of wear and proportionately smaller mandibles (Austin 2013). It becomes plausible that adoption of a softer, Roman style diet contributed to decreased attritional wear and a correspondingly increased level of caries, at least in the Fayum; the latter would have contributed to higher AMTL in the Late Dynastic.

## Nubia

Past bioarchaeological studies in Nubia were focused primarily on samples from the Mesolithic-Neolithic (14000-9000 BCE) transition and the much later Meroitic (600 BCE-350 AD), X-Group (AD 350-550), and Christian (AD 500-1500) periods (Beckett and Lovell 1994). Very few studies have included samples from the intervening periods (see Hillson 1979, Beckett and Lovell 1994). This study is the first to incorporate caries data from Nubian cemeteries, mainly prehistoric, that were previously unaccounted from the perspective of dental caries. It is thus in the unique position to bridge a decidedly long gap in the Nubian dental anthropological record and to contrast previous information with that derived from a more recent set of data.

On one hand, the results from caries frequencies comparisons in this analysis were in general agreement with those from previous studies in Nubia. Earlier studies described very low tooth caries frequencies of 1% in the Mesolithic/Neolithic, rising to

16-18% in Christian Nubian samples (Armelagos 1969, Greene et al. 1967, Greene 1972). Parametric results in this thesis are in complete agreement with the low prehistoric figure for tooth caries provided by these investigators. Furthermore, the aforementioned 1% was previously derived from a limited number of burials in the Wadi Halfa region of Lower Nubia. The present analysis confirms that the same figure can be also applied to a more representative number of prehistoric Nubian populations. Non-parametric statistics do not provide means and percentages and thus cannot be directly compared to results from these previous analyses. However, a comparison of mean ranks from Tables B1 and B3 shows that Nubian caries frequencies generally remained below those for Egypt.

Compared to the other samples, the prehistoric/preagricultural component of this study also showed some of the lowest mean ranks for individual caries. It thus appears that both prevalence and individual experience in dental caries remained relatively low for most of Nubian history. These dental disease indicators are perhaps expected if one considers subsistence and lifeways for these groups. Neolithic Nubians relied heavily on riverine resources and their diet included significant amounts of protein derived from marine foods. They also consumed a higher proportion of C4 plants (sorghum in particular) and retained high protein intake mainly in the form of bovine milk and blood (Caneva 1988, Caneva et al. 1993, Caneva and Gautier 1994). Although both populations exploited a variety of wild cereals and grasses, their diet included much less carbohydrates than later agricultural groups in both Egypt and Nubia. Dental studies in modern human populations suggest that diets rich in meat, milk, and cheese lower overall cariogenic risk, probably because of the calcium and phosphate content of these products.

Proteins and minerals absorbed into the mouth from these dietary sources can act as cariostatic agents by either slowing down enamel demineralization, enhancing remineralization, or a combination of the two processes (Mandel 1970, Duggal 1991, Johansson et al. 1994). It thus becomes probable that the decreased Nubian caries rates observed in this thesis were the consequence of a greater protein component in the Nubian diet relative to that consumed in Egypt.

Aside from agreement with published research, this analysis also provides new information on Nubian caries rates. In contrast to low mean ranks for tooth and individual caries, prehistoric Nubians had higher rates of AMTL. The magnitude of the difference was enough to statistically separate prehistoric Nubians from almost all (with the exception of Early Nubian) of the remaining samples in the Period contrast (Table B3). The significantly higher AMTL, in conjunction with low tooth and individual caries rates, indicated that higher AMTL may have been caused by factors other than caries, as has been suggested for males from R12 cemetery in Upper Nubia (Judd 2008). In this same sample, 60.1% of males exhibited significantly greater wear on anterior teeth than females in cases where both anterior and posterior teeth were available for analysis (Judd 2008). Furthermore, the angled, cupped-shape dental wear that characterized teeth from R12 was caused by rough, unprocessed food and/or meat, rather than cereals. This is suggestive of sexual division of labor in relation to processing or manipulation of a food substance with the anterior teeth by the males of that group (Crivellaro 2001, Judd 2008). Non parametric sex comparisons for Period (Table B7) showed that prehistoric Nubian males experienced higher AMTL than females, however this difference was not statistically significant. This result is in agreement with the equivalent parametric result from Table A8. Although there was no significance in either parametric or non-parametric results, the percentages on Table A8 showed that prehistoric Nubian males experience AMTL rates at almost a 3:1 ratio compared to females. According to the same table, males also show much higher, but not statistically significant, mean individual caries than the females in their group. Such results provide additional support to the tentative conclusion that the overall low dental caries indicators in prehistoric Nubians affected males in a disproportionate manner. This latter may have resulted from masticatory and dietary activities related to sex division in labor practices.

A closer look at inter-sample caries variability in this study also reveals considerable regional differences in prehistoric Nubian caries rates. These were not immediately apparent from Nubian caries comparisons between regions. Both parametric and non-parametric results indicate statistically significant differences in tooth and individual caries frequencies between the Upper Nubian (AKH, AKM, R12) prehistoric cemeteries and those from Lower Nubia (GRM, JSA). The differences in mean tooth caries between prehistoric Nubian cemeteries can be seen in Figure Seven below. Non-parametric results confirm the existence of significant differences in mean ranks for tooth and individual caries rates between GRM and JSA on the one hand, and the other three cemeteries on the other. No significant differences were found between GRM and JSA. The only significant differences among Upper Nubian prehistoric cemeteries occur for mean AMTL ranks between AKH on one hand, and AKM together with R12 on the other.

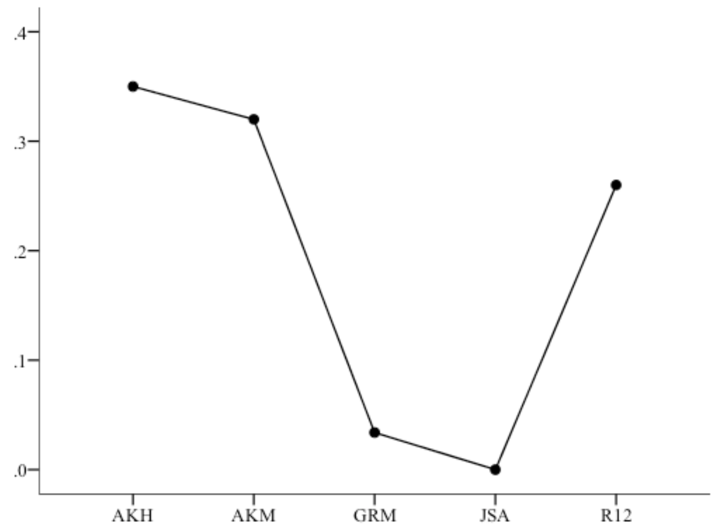


**Figure 7.** Mean tooth caries in prehistoric Nubians.

Dental wear, and attrition in particular, can again be invoked as a potential factor in these differences. Extreme levels of attritional wear have been observed by previous researchers on individuals from Mesolithic Wadi Halfa in Lower Nubia (Greene et al 1967, Armelagos et al. 1984) as well as the Neolithic cemeteries of Saggai (Coppa and Macchiarelli 1983) and R12 (Crivellaro 2001, Judd 2008) in Upper Nubia. However, dental anthropological assessment of the sample from Gebel Ramlah in Lower Nubia (also part of this study) showed that the individuals there possessed good overall dental health with minor attritional wear (Kobusiewicz et al. 2004). At the moment the role of attrition remains unclear. Future excavations and increased samples from these cemeteries can allow for quantitative analyses of caries and wear patterns on a larger scale.

Another explanation for caries differences in Nubia may be offered by the apparent cultural variability on regional level. The archaeological record provides evidence for ceramic, lithic and mortuary differences between the two regions that existed until late in Nubian history. The Mesolithic and Neolithic of Upper Nubia and central Sudan by characterized by, among other things, marked regional variability in pottery decoration styles, though most share the basic motifs of the ‘wavy’, or ‘dotted’, line decorations (Caneva et al. 1993). Variability between the two regions is also evident in mortuary practices in relation to body positions, orientation, and facing within the graves (Bonnet 1991, Geus 1991, Peressinotto et al. 2004, Irish 2008). In Meroitic times, burial differences between Upper and Lower Nubia were concentrated on type of superstructure. In the north, pyramidal superstructure forms predominated. The south saw widespread use of the tumulus superstructure, a practice almost never encountered in Lower Nubia (Edwards 1998). It is thus likely that caries differences between Upper and Lower prehistoric Nubian cemeteries was a result of cultural factors interacting with diet, wear, and levels of dental disease.

Temporal comparisons of Nubian caries frequencies also revealed some other unique information. According to the results of this analysis the highest caries frequencies in Nubia were observed in the Early Nubian sub-component. When compared to the Nubian and the Egyptian periods, Early Nubia has the second-highest caries indicators, only falling below those for the Late Dynastic (Table B3). The Early Nubian component of this study consists of the early agriculturalists of the A- and C-Group together with the individuals from cemetery HK27C at Hierankopolis. Parametric statistics indicate that HCG had abnormally higher tooth and individual caries, 0.8 and 11.7, respectively. These values were significantly greater than those for the A- and C-Group, and much higher than any result produced in these comparisons. Individual HCG caries rates were 37.5%, or 18 in 48 individuals. In comparison, the highest such figure produced in any other comparison was 23.9% for Lower Nubia. When compared to all other cemeteries, HCG again showed highest averages for both tooth and caries per individual, together with HAW (Figs. Five and Six). In combination with the expected caries results for A- and C-Group (see discussion in Chapter Two), it is clear that caries values for Early Nubia are elevated by the unusually high caries frequencies for HCG. This is similar to the way HAW affected the results for Lower Egypt and can be considered another example of how sample selection can influence the results of quantitative caries analyses.

The effect that HCG exercises on Early Nubian caries frequencies can be seen graphically in Figure Eight, which depicts mean tooth caries frequencies by Period when HCG is excluded from the comparison. When Early Nubian tooth caries is compared to that on Table A4, a sharp decrease from 0.35 to 0.15 can be observed. Thus when HCG is excluded from comparisons, the mean tooth caries for Early Nubia falls to a level that approximates preagriculturalists. The cemetery from HK27 is unusual because, although it was located deep in Egyptian territory, mortuary and biological evidence such as tomb superstructure, burial position, dress, jewelry, and dental non-metric traits, identified many of the occupants as ethnic C-Group Nubians (Friedman 2007, Irish and Friedman 2010). Previous research has indicated that the HCG group lived prosperous and peaceful lives, was well integrated into their community, and most likely shared the diet and daily habits of their contemporary Egyptians (Friedman 2007, Judd 2008, Irish and Friedman

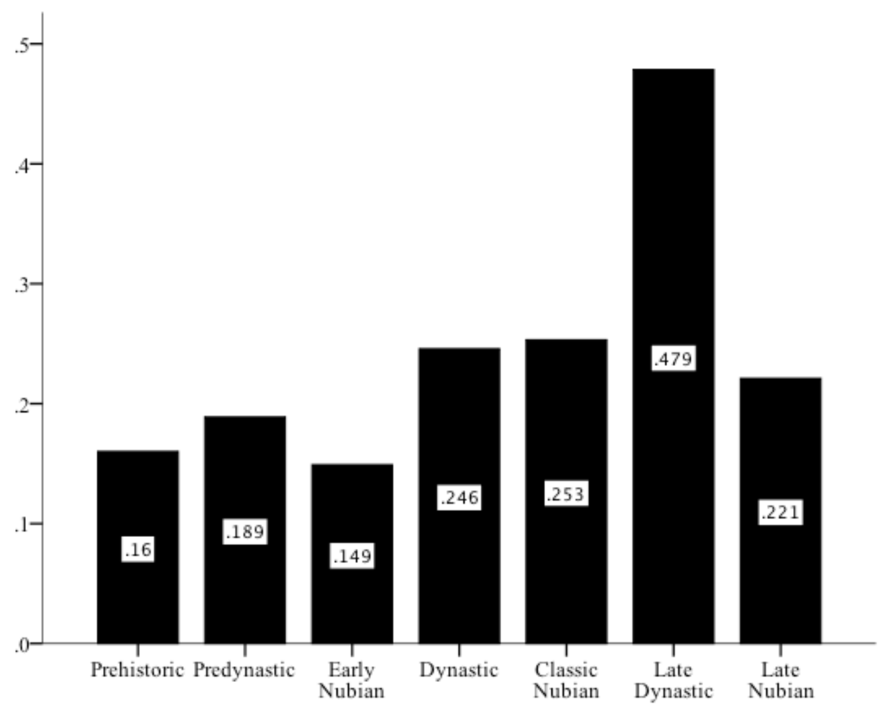


**Figure 8.** Mean tooth caries for Period excluding HCG.

2010). This study provides preliminary evidence that these people differentiated along a diet with a much higher carbohydrate component than either their contemporary Nubians or Egyptians. Whether this was related to a particular place they held in society, ethnic identity, or other culturally assigned diacritica can be tested by future research. One possible direction could explore variability in mortuary ritual and offerings among the 18 carious individuals from the HCG sample. This may help provide a better understanding of intra-sample variability in relation to caries frequencies in this group.

If we accept that HCG represents an outlier, and that caries frequencies in the A- and C-Group were as low as depicted in Figs. Five and Six, then the greatest increase in Nubian caries prevalence occured during the Classic Nubian phase. Three (KER, KAW, KUS) of the four samples (PHA) that comprise the Classic Nubian component came from Upper Nubia and they represent the Kerma cultural phase (KER, KAW) together with early Meroitic (Napatan) horizons (KUS). The site of Kerma is situated 20 km south of the Third Cataract, on the right bank of the Nile in Upper Nubia (Chaix and Grant 1993).

Archaeobotanical evidence from the type-site during the Classic Kerma period showed that plant remains were dominated by the staple Pharaonic winter crops of emmer wheat (*Triticum diococcum*) and barley (*Hordeum vulgare*). These were supplemented with remains from fruits like melon, watermelon, figs, dates, and doum palms (Fuller 2004). Although paleopathological evaluations of Kerma and Pharaonic Nubians have increased in the last decade (Judd 2004, Buzon 2006, Buzon and Judd 2008), little information exists on the dental pathologies experienced by these people. Buzon and Bombak (2010) examined 1891 teeth from the same Kerma sample in this study and reported 5% of them to be carious. By contrast, results in this study indicated tooth caries frequencies of ~2%. In any case, caries information in this thesis provides additional biological evidence for agricultural intensification during the Kerma period and also confirmed that these people were exposed to increased cariogenic risk relative to their Nubian predecessors.

Nubian caries frequencies witnessed a marked, but statistically non-significant, reduction in the post-Kerma period. The average for carious teeth decreased from 0.46 in the Kerma sample to 0.08 in the Kushite and 0.02 in the Meroitic components of this study. Mean caries per individual and AMTL for the latter were equally low, 0.086 and 0.14 respectively. The Meroitic culture encompassed intense agriculturalists and it is during this period that sorghum was domesticated. This fact, in addition to the adoption of the water wheel for irrigation and the existing cultivation of wheat and barley, must have greatly increased both agricultural output and carbohydrate consumption (Martin et al. 1984, Fuller 2004). It is thus of interest that the intensive Meroitic agriculturalists in this study showed caries frequencies that fell below those of preagricultural hunters-gatherers. One explanation for this could be offered by sample bias. In the MER sample, only one in 40 individuals (2.5%) had caries. Alternatively, it is possible that the sample was underscored for caries and a second appraisal is necessary. At the same time there is some support in previous literature for the Classic Nubian caries relationships observed here, at least on a relative scale. Rose and co-workers (1993) published a comprehensive review of dental anthropology in the Nile Valley and depicted the relationship between advanced dental wear and caries in a series of late Lower Nubian cemeteries. The authors of the study used samples from cemeteries 6B16 (Meroitic), NAX and 2413 (X-Group) , 6B13 and 6G8 (Christian) (Rose et al. 1993). The caries relationship between the human remains from Meroitic and X-Group cemetery approximated the one shown here, i.e. the lower Meroitic caries frequencies were succeeded by higher caries in the X-Group. However it is not clear what the ‘Percent’ category represents in Rose et al. (1993). If by that the authors meant 40% + carious teeth in 6B16 (as indicated by Fig. Three in the article), then the two studies are far apart in their calculations. The positive relationship between caries and wear detected by these authors would also imply that one should expect low levels of wear in MER. This assumption can be further tested by future studies that compare levels of dental caries and dental wear in the same MER sample used in this study.

The final note to this discussion must again highlight the importance of intra-sample variability in the interpretation of quantitative caries results. As was repeatedly shown here, caries rates can vary considerably between culturally related and geographically adjacent cemeteries. This reality was demonstrated also by Hillson (1979), Ibrahim (1987), and Rose et al. (1993), where considerable caries differences were observed. It is possible that the discrepancy in dental caries between the MER in this study and Rose et al. (1993) can be due to cemetery variability since the former came from Semna and the latter from Wadi Halfa. This latter also highlights the importance of analyzing variation between individual cemeteries of the same culture, as has been repeatedly stated by these previous investigators (Hillson 1979, Martin et al. 1984, Rose et al. 1993). In this context, MER caries frequencies should be contrasted with that from other Meroitic cemeteries in both Upper and Lower Nubia. This will generate a better understanding of Meroitic caries as a whole.

# CHAPTER 8

## SUMMARY AND CONCLUSIONS

Dental caries is a truly ancient disease with a long history of colonization in the mammalian mouth. It is also the most commonly diagnosed disease in human skeletal material. Dental caries rates have been closely associated with consumption of dietary carbohydrates and can provide a reliable indicator of adaptive shifts from hunting-gathering to agricultural economies. Diet is a social and biological process that is regulated by a number of interactions between members. The relations formed through those interactions in a stratified society are used to exert power over others, which in turn creates differential allocation of resources, benefits, and risks (Schell 1997). Caries rate variability between segments of society, as in sex, age, or social class, can help illuminate those inequalities. Thus information on caries can in certain cases provide insight into social structure and power relations in a group.

This thesis attempted to apply this biocultural perspective to quantitative analyses of caries frequencies in a large number of ancient Egyptians and Nubians. The 1842 individuals that comprised the skeletal population for this study were derived from 17 Egyptian and 15 Nubian cemeteries, were of mixed sex, and represented a cross section of Egyptian and Nubian societies over a long period of time (14000 BCE-1500 CE). In addition, this study included caries data from four Neolithic cemeteries that had not been previously evaluated from the perspective of dental caries. The temporal span covered by this thesis is extremely long and encompasses major biocultural changes in the history of the two countries, such as the transition from hunting and gathering to sedentism and agriculture, the introduction of pastoralism, and the emergence of organized state, inter-state commerce, and stratified society.

Caries frequencies rates are used as indicators to explore several broad research questions relating to dental caries, as well as dental disease, in Egypt and Nubia. These questions were: 1) What are the overall temporal trends in caries frequencies that can be observed in the various phases of the cultural history in Egypt and Nubia?; 2) How do the results in this thesis compare to what has been published on caries differences between preagriculturalists and agriculturalists? Are there any caries patterns that can be observed among the preagriculturalist component?; 3) How can inter-sample caries variability contribute to our understanding of caries rates during the prolonged and culturally diverse Dynastic period in Egypt?; and 4) Can we assess differential access to resources according to sex and/or social status based on the caries findings in this analysis?

In relation to the first research question this thesis is in overall agreement with results from previous analyses of temporal trends and changes in Egypto-Nubian dental caries. Nevertheless some new information is also provided. Dental caries rates remained low in Egypt and Nubia compared to other agricultural populations but increased through time. In both regions the increase in dental caries corresponded to periods later in history when agricultural intensification took place. Although the differences were not statistically significant, AMTL rates in Egyptians and Nubians surpassed tooth and individual caries rates by more than 3:1. Thus dental caries was not a primary agent in AMTL and other, wear-related dental pathologies were involved (such as periodontal disease). Egyptians experienced significantly higher mean tooth caries than Nubians, but

Nubian females were affected by dental caries in a decidedly more uneven fashion than their Egyptian counterparts.

Although there were few significant overall differences in caries prevalence between Egypt and Nubia, a different picture emerged from regional (Region) and temporal (Period) comparisons. In Egypt significant differences in dental caries existed between the Late Dynastic and Intensive Agriculturalist samples on one hand, and earlier periods on the other. These differences centered on samples from Lower Egypt, a region with significantly higher dental caries prevalence when compared to the other three regions (Upper Egypt, Lower Nubia, and Upper Nubia). Lower Egypt also had significantly higher AMTL. These indicators reveal an overall dental profile among Lower Egyptians that is of lesser quality when compared to the other regions in the study. Over half from the individuals in the Lower Egyptian component came from Late Dynastic cemeteries, which, in this analysis, are equivalent to the Greco-Roman era in Egyptian history. Thus higher caries prevalence in Lower Egyptian samples may be a reflection of the agricultural intensification practices and increased carbohydrate consumption that occurred during the Ptolemaic and Roman periods.

In Nubia, the highest dental caries frequencies were encountered among the Kerma agriculturalists of the First Kushite kingdom and the Middle Kingdom urban population from cemetery HK27C in Egypt. Dental caries among Nubians fell appreciably, but not significantly, in the succeeding Meroitic sample. The Meroitic phase in Nubian history represented a time of political centralization, agricultural intensification, and population growth. Thus results for the Meroitic component in this study appear inconsistent with this context. It is possible that the results were influenced by sample bias since the MER sample was obtained from a single location in Semna South (Irish 2005). Alternatively a re-evaluation of Meroitic dental caries rates may be necessary using larger and more representative samples. Dental caries and AMTL increased in the succeeding X-Group, reaching significant proportions during the Chriatian era. This finding was consistent with previous research showing an overall deterioration of oral health (including increase in caries) during this period (Armelagos 1966, Beck and Greene 1989).

In relation to the second research question, results in this thesis showed that Nubian hunter-gatherers had low rates of tooth caries, individual caries, and AMTL. These results were in agreement with previous research on Nubian prehistoric caries rates. However, statistical comparisons among the five prehistoric/preagricultural samples showed that significant differences in dental caries existed between Upper and Lower Nubian cemeteries, as well as between the males and females of the group as a whole. It is possible that this sex dimorphism in dental caries was not related to diet and may have involved use of teeth as tools by the males of the group (Crivellaro 2001). Statistical significance among the hunting-gathering samples was found to exist between the oldest sample from Jebel Sahaba (JSA) and the three later samples from Upper Nubia (AKM, AKH, R12). The second Lower Nubian sample, from Neolithic Gebel Ramlah (GRM), clustered closely with JSA although the two samples were separated temporally by several millennia. At the same time the Upper Nubian Mesolithic sample (AKM) had significantly higher caries prevalence than their Lower Nubian equivalents and clustered closely with the much later Neolithic cemeteries from the same region. These dental caries patterns indicated that hunter-gatherer subsistence included a higher amount of carbohydrate intake in Lower Nubia, and that this pattern preceded the Neolithic transition in the region.

The third research question sought to evaluate previous information for considerable regional heterogeneity in Dynastic dental caries rates (Hillson 1979, Ibrahim 1987) and consider how this variability affects our interpretation of results from dental caries analyses. In agreement with previous results, Dynastic dental caries rates (tooth as well as individual) in this analysis were shown to be highly variable. However, the statistically significant dental caries differences among Dynastic cemeteries could not always be explained by the overall temporal trend for an increase in dental caries prevalence from earlier to later periods.

For example, individuals from the Middle Kingdom cemetery at Lisht (Lower Egypt) had significantly fewer teeth affected by caries than individuals from the earlier Old Kingdom cemetery at Saqqara (also in Lower Egypt). As was discussed in Chapter Four, analyses of craniodental data from a number of Egyptian cemeteries showed that LIS was genetically divergent from all other Egyptian cemeteries (Irish 2006). It is thus possible that dental caries frequencies at LIS were not representative of those in the general population at the time. In this study, this latter was exemplified by the unusually high dental caries indicators in the samples from HCG and HAW. Dental caries indicators (but not AMTL) for the various categorical variables (Region, Period etc) were driven upward when these latter samples were included in the comparisons. This thesis provided additional support to the well-attested fact that results from dental caries analyses in Egypt could be highly influenced by sample selection and/or availability (Hillson 1979, Rose et al. 1993). Thus studies of inter-cemetery variability in ancient Egyptian dental caries may produce more meaningful results if they focus on comparisons among contemporaneous cemeteries from the same or different region(s), as opposed to temporal comparisons over long periods of time.

Finally, this thesis can only make tentative inferences to differential access to resources as reflected by the uneven distribution of dental caries according to sex and/or social status. As was discussed in Chapter Five, the lower and middle status sub-components of the variable Status are composed of few and temporally restricted samples and hence cannot be considered representative of the entire timespan covered by this thesis. The upper status component had significantly higher tooth and individual caries prevalence, as well as AMTL, than both middle and lower but these results need further testing using larger and more representative samples. Inferences to dental caries for the upper status individuals can be made with greater confidence because they were greater in number and more spread out over time than their middle and lower status counterparts. Relative to other individuals of lower or middle status, upper status individuals had high overall dental caries rates and suffered from relatively high AMTL. These results indicated that individuals of higher social status in ancient Egypt may have had greater access to cariogenic foodstuffs, and that higher social status did not necessarily correspond to better dental health.

Overall, sex differences in dental caries were small for both Egypt and Nubia. For most of the time period covered in this study (12000 BCE-1450 CE) it appeared that both males and females had a more or less equal share in the cariogenic foods that contributed to dental caries rates. A few statistically significant differences did occur and were important in highlighting once more the usefulness of inter-regional and inter-cemetery dental caries comparisons. These differences included higher individual caries for the males of the Preagricultural/Prehistoric category. The latter also showed considerably (but not significantly) higher AMTL, thus presenting a poorer overall dental profile than the females in their group. Interestingly, sex-based dental caries patterns showed a drastic reversal during the succeeding Early Nubian period. The percentage of Early Nubian females with tooth caries increased from 45.4% to 69.9% while that of males decreased from 54.7% to 30.1%. Although this difference was not statistically significant, it suggested that the advent of agriculture in Nubia also caused a decisive shift in the distribution of dental caries according to sex at the expense of Nubian females.

Significantly higher tooth caries prevalence was also experienced by Upper Egyptian females compared to their male counterparts. This result was insightful considering that among the four regions in this study Upper Egypt showed some of the lowest overall rates for dental caries. Thus considerable sex inequality in dental caries can occur even under conditions of low overall prevalence of the pathology in the population. The last significant sex difference in this study was observed in AMTL rates for the males of the Late Dynastic component. The Late Dynastic period saw increased dental caries, which most likely was due to the agricultural intensification and increased carbohydrate and sugar consumption during this period. Higher caries in Late Dynastic samples was accompanied by a worsening of overall dental health as indicated by the AMTL rates, and this deterioration affected the males in a disproportionate way. Interestingly, AMTL sex dimorphism patterns in the Late Dynastic showed a complete reversal from the earlier Predynastic period when it was females that had considerably (but not significantly) higher AMTL prevalence than males (see Tables in Results). This last finding suggested that the economic and social re-organization of Egyptian culture that took place under the Ptolemies and the Romans profoundly affected overall male dental health in a negative way. As a final word, this thesis operated under the assumption that higher prevalence of caries among femals, whenever found, was the consequence of a sexual division of labor and food preparation. As was discussed more extensively in Chapter Three, data from living human populations has inferred at least some degree of relationship between higher female caries and physiological events such as menstruation, childbirth, and menopause. Whetether these life events also contributed to elevated prevalence of caries among females in ancient Egypt and Nubia cannot be ascertained within the confines of this analysis. Future research on living human populations may be able to provide a more comprehensive picture about the relationship between female dental caries and female reproductive and/or life events.

## Future Research

While this study has provided important information, it is by no means the last attempt in caries frequencies analyses for ancient Egyptians and Nubians. From the discussion so far, it became evident that inter-cemetery caries comparisons were more meaningful in interpreting cultural and dietary changes than comparisons between large, temporal or cultural units. This region-specific aspect of caries variability in Egypt and Nubia has also been discussed by other investigators (Martin et al. 1984, Hillson 1979, Greene 2006). Inter-cemetery or inter-regional comparisons could thus be used to test hypotheses organized along the significant findings discussed earlier. For example, comparisons of caries prevalence among samples from various locations in Lower Nubia could test the hypothesis that the geomorphologic features of the Batn el Hajar and the Second Cataract presented geographic barriers that affected caries frequencies distribution in human groups located to the north or south, as was suggested in this thesis. Similarly, comparisons of caries among select samples from Upper and Lower Egypt could ascertain the impact of Greco-Roman dietary habits and immigration on local Egyptian diet. Regional comparisons between temporally related samples could also provide a better understanding of the cultural background that shaped the exceptionally high dental caries encountered at HAW and HCG.

However, caries is only but one indicator of dental disease and future research should also include dental wear and stable isotope analyses, whenever these are feasible. Considering the important relationship between caries and attrition, caries frequencies cannot be fully understood without information on the type and grade of dental attrition. Such information could help explore whether the considerable caries differences between prehistoric Upper and Lower Nubian cemeteries are related to attrition. If levels of dental wear correlated with caries rates in samples from the two regions, and if wear was due to non-masticatory tooth use as indicated previously, then it may be possible that Upper and Lower Nubia were occupied by different groups practicing variable ways of non-dietary use of teeth.

Additionally, stable isotope analysis of skeletal remains could be used to frame results from caries analyses within a wider dietary context. Stable isotope and trace-element analyses can differentiate between consumption of C3 and C4 plants, as well as provide a measure for animal and marine protein in the diet (Sillen and Kavanagh 1982, Palmieri 1983, Iacumin et al.1996, Iacumin et al. 1998, Van der Merwe 1992, White et al. 1999, Katzenberg 2000). This line of research, in combination with caries data, could be particularly useful in a more complete understanding of the role of cattle as dietary item in the Kerma culture of Upper Nubia, as stated earlier in this section. Finally, a greater understanding of overall dental caries prevalence could be derived from studies analyzing tetracycline levels in existing Egyptian and Nubian samples. As was discussed earlier, tetracyclines were formed naturally by soil bacteria in Egyptian and Nubian beer and bread and may have played an important cariostatic role. Other ecological factors contributing to dental caries variability could be explored by geochemical analyses targeting fluorine levels in ancient Nilotic sediments. As was discussed in Chapter Three, fluoride occurs naturally in water and can play an important part in the re-mineralization of dental enamel. However determination of mineral content in ancient soils can be hampered by the heavy sedimentation and alluvial deposition in the Nile Valley over the millennia and hence this last avenue of research is likely difficult to operationalize.

**REFERENCES**

Achilli A, Bonfiglio S, Olivieri A, Malusa A, Pala M, Kashani BH, Perego UA, Ajmone-Marsan P, Liotta L, Semino O, Bandelt HJ, Ferretti L, Torroni A. 2009. The multifaceted origin of taurine cattle reflected by the mitochondrial genome. PLoS ONE 4(6):e5753

Adams B. 1996. Elite graves at Hierankopolis. Spencer J, editor. Aspects of Early Egypt. British Museum Press. p 1-15.

Adam S. 1981. The importance of Nubia: A link between Central Africa and the Mediterranean. In: Mokhtar G, editor. General History of Africa, Vol 2: Ancient Civilizations of Africa. p 227-244.

Adams WY. 1970. A re-appraisal of Nubian culture history. Orientalia 39:269-279.

Adler AJ, Turner II CG. 2000. Dental caries in prehistoric California Indians: A comparative test of the Jomon agriculture hypothesis. American Journal of Physical Anthropology Supplement 30:91-92.

Allen LH. 2005. Multiple micronutrients in pregnancy and lactation: An overview. American Journal of Clinical Nutrition 81(supplement):1206S-1212S.

Ambrose SH, Buikstra J, Krueger HW. 2003. Status and gender differences in diet at Mound 72, Cahokia, revealed by isotopic analysis of bone. Journal of Anthropological Archaeology 22:217-226.

Angel LJ. 1944. Greek teeth: Ancient and modern. Human Biology 16(4): 283-297.

Armelagos GJ. 1966. Frequency of dental caries in four archaeological populations from Sudanese Nubia. American Journal of Physical Anthropology 25: 210.

Armelagos GJ. 1969. Disease in ancient Nubia. Science 163(3864): 255-259.

Armelagos GJ. 2003. Bioarchaeology as anthropology. Archaeological Papers of the American Anthropological Association 13(1):27-40.

Armelagos GJ, Jacobs KH, Martin DL. 1981. Death and demography in prehistoric Sudanese Nubia. In: Humphreys SC, King H, editors. Mortality and Immortality: The Archaeology and Anthropology of Death. Proceedings of A Meeting of The Research Seminar in Archaeology and Related Subjects Held At The Institute of Archaeology, London University. London:Academic Press. p 33-57.

Armelagos GJ, Van Gerven DP, Martin DL, Huss-Ashmore R. 1984. Effects of nutritional change on the skeletal biology of northeast African (Sudanese Nubian) populations. In: Clark JD, Brandt SA, editors. From Hunters Farmers: The Causes and Consequences of Food Production in Africa. University of California Press. p 132-146.

Armelagos GJ, Kolbacher K, Collins K, Cook J, Krafeld-Daugherty M. 2001. Tetracycline consumption in prehistory. In: Nelson M, Hillen W, Greenwald RA, editors. Tetracyclines in Biology, Chemistry, and Medicine. Birkhauser-Verlag. p 219-236.

Armelagos J, Van Gerven DP. 2003. A century of skeletal biology and paleopathology: Contrasts, contradictions, and conflicts. American Anthropologist 105(1):53-64.

Aufderheide AC, Cartmell LL, Zlonis M, Horne P. 2003. Chemical dietary reconstruction of Greco-Roman mummies at Egypt's Dakleh Oasis. Journal of the Society for the Study of Egyptian Antiquities 30:1-8.

Austin A. 2013. From bread to porridge: An analysis of dietary shifts during Roman rule at Karanis, Egypt.

Barakat H, Fahmy AG. 1999. Wild grasses as 'Neolithic' foodresources in the eastern Sahara. A review of the evidence from Egypt. In: Van der Veen M, editor. The Exploitation of Plant Resources in Ancient Africa. p 33-46.

Barich BE. 1993. Culture and environment between the Sahara and the Nile in the early and mid-Holocene. In: Krzyzaniak L, Kobusiewitz M, Alexander J, editors. Environmental Change and Human Culture in the Nile Basin and Northern Africa Until the Second Millennium BC. Poznan Archaeological Museum. p 171-183.

Barich BE. 2002. Cultural responses to climatic changes in North Africa: Beginning and spread of pastoralism in the Sahara. In: Hassan FA, editor. Droughts, Food, and Culture. Ecological Change and Food Security in Africa's Later Prehistory. New York: Kluwer Academic/Plenum Publishers. p 209-223.

Bard KA. 1989. The evolution of social complexity in Predynastic Egypt: An analysis of the Naqada cemeteries. Journal of Mediterranean Archaeology 2:223-248.

Bard KA. 1992. Toward an interpetation of the role of ideology in the evolution of complex society in Egypt. Journal of Anthropological Archaeology 11:1-24.

Bard KA. 1994. The Egyptian Predynastic: A review of the evidence. Journal of Field Archaeology 21(3):265-288.

Bard KA. 2000. The emergence of the Egyptian state. In: Shaw Ian, editor. The Oxford History of Ancient Egypt. Oxford University Press. p 57-82.

Bard KA. 2008. An Introduction to the Archaeology of Ancient Egypt. Blackwell Publishing.

Bassett EJ, Keith MS, Armelagos GJ, Martin DL, Villanueva AR. 1980. Tetracycline-labeled human bone from ancient Sudanese Nubia (AD 350). Science, New Series 209(4464):1532-1534.

Beck R, Greene DL. 1989. Dental disease among medieval Christian Sudanese from the Batn-el-Hajar. American Journal of Physical Anthropology 78: 190.

Beckett S, Lovell NC. 1994. Dental disease evidence for agricultural intensification in the Nubian C-Group. International Journal of Osteoarchaeology 4:223-240.

Bentley GR, Paine RR, Boldsen JL. 2001. Fertility changes with the prehistoric transition to agriculture: Perspectives from ecology and paleodemography. In: Ellison PT, editor. Reproductive Ecology and Human Evolution. New York: Aldine de Gruyter. p 203-231.

Bernaby E, Sheiham A, Sabbah W. 2009. Income, income inequality, dental caries, and dental care levels: An ecological study in rich countries. Caries Research 43:294-301.

Bettinger RL, Barton L, Richerson PJ, Boyd R, Hui W, Won C. 2007. The transition to agriculture in northwestern China. Developments in Quaternary Sciences 9:83-101.

Blackburn T. 1975. December's Child: A book of Chumash oral narratives. Berkeley: Univeristy of California Press.

Bonnet C. 1991. Upper Nubia from 3,000-1,000 BC. In: Davies WV, editor. Egypt and Africa. Nubia from Prehistory to Islam. British Museum Press. p 112-117.

Bourriau J. 1991. Relations between Egypt and Kerma during the Middle and New Kingdoms. In: Davies WV, editor. Egypt and Africa. Nubia from Prehistory to Islam. British Museum Press. p 129-144.

Bourriau J. 2000. The Second Intermediate Period (c.1650-1550 BC). In: Shaw I, editor. The Oxford History of Ancient Egypt. Oxford University Press. p 172-206.

Bretz WA, Corby PM, Schork NJ, Robinson MT, Coelho M, Costa S, Melo Filho MR, Weyant RJ, Hart TC. 2005. Longitudinal analysis of heritability for dental caries traits. Journal of Dental Research 84(11): 1047-1051.

Brothwell DR. 1963. The macroscopic dental pathology of some earlier human populations. In Brothwell DR, editor. Dental Anthropology. Oxford Pergamon Press. p 271-288.

Brown LR, Dreizen S, Handler S. 1976. Effects of selected caries preventive regimens on microbial changes following irradiation-induced xerostomia in cancer patients. In: Microbial aspects of dental caries. Microbiol Abstr 1, Sp. Suppl. p 275.

Brown PJ, Inhorn MC, Smith DJ. 1996. Disease, ecology, and human behavior. In: Sargent CF, Johnson TM, editors. Medical Anthropology: Contemporary Theory and Methods. Westport, CT: Praeger. p 183-218.

Butzer KW. 1959. Environemnt and human ecology in Egypt during Predynastic and early Dynastic times. Bulletin de la Société de géographie d'Egypte 32:4-87. Cairo.

Butzer KW. 1960. Archaeology and geology in ancient Egypt. Science 132:1617-1624.

Butzer KW. 1976. Early Hydraulic Civilization in Egypt. A Study in Cultural Ecology. The University of Chicago Press.

Butzer KW. 1980. Pleistocene history of the Nile Valley in Egypt and Lower Nubia. In: Faure H, editor. The Sahara and the Nile. Rotterdam: AA Balkema. p 253-280.

Buzon MR. 2006. Health of the non-elites at Tombos: Nutritional and disease stress in New Kingdom Nubia. American Journal of Physical Anthropology 130: 26-37.

Buzon MR, Judd MA. 2008. Investigating health at Kerma: Sacrificial versus nonsacrificial individuals. American Journal of Physical Anthropology 136:93-99.

Buzon MR, Bombak A. 2010. Dental disease in the Nile Valley during the New Kingdom. International Journal of Osteoarchaeology 20:371-387.

Caglar E, Kuscu OO, Sandalli N, Ari I. 2007. Prevalence of caries and tooth wear in a Byzantine population ($13^{th}$ c. AD) from northwest Turkey. Archives of Oral Biology 52:1136-1145.

Calcagno JM. 1986. Dental reduction in post-Pleistocene Nubia. American Journal of Physical Anthropology 70:349-363.

Caneva I. 1988. Prehistoric settlements along the Nile between Kabbashi and Geili. In: Caneva I, editor. El Geili: The History of a Middle Nile Environment 7000 BC-AD 1500. Cambridge Monographs in African Archaeology 29. Oxford: B.A.R. p 321-344.

Caneva I, Garcea EAA, Gautier A, Van Neer W. 1993. Pre-pastoral cultures along the central Sudanese Nile. Quartenaria Nova 3:177-252.

Caneva I, Gautier A. 1994. The desert and the Nile: Sixth millennium pastoral adaptations at Wadi El Kenger (Khartoum). Archaeologie du Nile Moyen 6:65-92.

Carlson DS, Van Gerven DP. 1977. Masticatory function and post-Pleistocene evolution in Nubia. American Journal of Physical Anthropology 46:495-506.

Carlson DS, Van Gerven DP. 1979. Diffusion, biological determinism, and biocultural adaptation in the Nubian corridor. American Anthropologist, New Series 81(3):561-580.

Chaix . 1993. The archaeozoology of Kerma (Sudan). In: Davies WV, Walker R, editors. Biological Anthropology and The Study of Ancient Egypt. London: p 175-185.

Chaix L, Grant A. 1993. Paleoenvironment and economy at Kerma, northern Sudan, during the third millennium BC: Archaeozoological and botanical evidence. In: Krzyzaniak L, Kobusiewitz M, Alexander J, editors. Environmental Change and Human Culture in the Nile Basin and Northern Africa Until the Second Millennium BC. Poznan Archaeological Museum.

Chamberlain A, Whitkin A. 2003. Early Neolithic diets: Evidence from pathology and wear. In: Pearson MP, editor. Food, Culture, and Identity in the Neolithic and early Bronze Age. Oxford: BAR International Series. p 53-58.

Clark DJ. 1971. A re-examination of the evidence for agricultural origins in the Nile Valley. Proceedings of the Prehistoric Society 37:34-79.

Clark DJ. 1980. Human populations and cultural adaptations in the Sahara and Nile during prehistoric times. In: Williams MAJ, Faure H, editors. The Sahara and the Nile. Rotterdam: AA Balkema. p 527-582.

Clement AJ. 1958. The antiquity of caries. British Dental Journal 104(4):115-122.

Close AE. 2002. Sinai, Sahara, Sahel: The introduction of domestic caprines to Africa. In: Tides of the Desert. Contributions to the Archaeology and Environmental History of Africa in Honour of Rudolph Kuper. Cologne: Heinrich Barth Institute. p 459-469.

Cook M, Molto EL, Anderson C. 1989. Fluorochrome labeling in Roman period skeletons from Dakleh Oasis, Egypt. American Journal of Physical Anthropology 80:137-143.

Coppa A, Macchiareli R. 1983. Human skeletal remains from the Mesolithic site of Saggai 1 (Sudan). Origini 12:116-139.

Costa Jr. RL. 1980. Incidence of caries and abscesses in archaeological Eskimo skeletal samples from Point Hope and Kodiak Island, Alaska. American Journal of Physical Anthropology 52:501-514.

Constant MA, Phillips PH, Elvehjem CA. 1952. Dental caries in the cotton rat. The Journal of Nutrition.

Crawford J. 1979. Food: Tradition and change in Hellenistic Egypt. World Archaeology 11(2):136-146.

Cremaschi M, Di Lernia S. 1999. Holocene climatic changes and cultural dynamics in the Libyan Sahara. African Archaeological Review 16(4):211-238.

Crivellaro F. 2001. Human skeletal remains from R12, a Late Neolithic cemetery in the northern Dongola Reach (Sudan): A descriptive anthropological study. In: Salvatori S, Usai D, editors. First Season of Excavation at the R12 Late Neolithic Cemetery in the northern Dongola Reach (Kawa, Sudan):Preliminary Report. Rivista di Archaeologia. Roma: p 57-68.

Cucina A, Tiesler V. 2003. Dental caries and antemortem tooth loss in the northern Peten area, Mexico: A biocultural perspective on social status differences among the Classic Maya. American Journal of Phyical Anthropology 122:1-10.

Cucina A, Cantillo CPS, Thelma S, Tiesler V. 2012. Carious lesions and maize consumption among the prehispanic Maya: An analysis of a coastal community in northern Yucatan. American Journal of Physical Anthropology 145:560-567.

Cuozzo FP, Sauther ML. 2012. What is dental ecology? American Journal of Physical Anthropology 148:163-170.

David AR. 1985. The Manchester Mummy Project. Archaeology 38(6):40-47.

Davies V. 2003. Kush in Egypt: A new historical inscription. Sudan and Nubia 7:52-54.

Dean MC, Reid DJ. 2001. Perikymata spacing and distribution on hominid anterior teeth. American Journal of Physical Anthropology 116:209-215.

Deeley K, Letra A, Rose EK, Brandon CA, Resick JM, Marazita ML. 2008. Possible association of Amelogenin to high caries experience in a Guatemalan-Mayan population. Caries Research 42:8-13.

DeWitt SN, Bekvalac H. 2010. Oral health and frailty at the Medieval English cemetery of St Mary Graces. American Journal of Physical Anthropology 142:341-354.

Dixon DM. 1972. Masticatories in ancient Egypt. Journal of Human Evolution 1: 443-449.

Dougherty SP, Friedman RF. 2005. Sacred or mundane: Scalping and decapitation at Predynastic Hierankopolis. In: Midant-Reynes B, Tristant Y, editors. Egypt at Its Origins 2. Proceedings of the International Conference ‘Origin of the State, Predynastic, and Early Dynastic Egypt’, Toulouse,France. Leuven-Peeters:331-338.

Duggal MS. 1991. The relationship between diet and dental caries. The Saudi Dental Journal 3(1):24-29.

Dupras TL, Schwarcz HP, Fairgrieve SI. 2001. Infant feeding and weaning practices in Roman Egypt. American Journal of Physical Anthropology 115:204-212.

Duyar I, Erdal YS. 2003. A new approach for calibrating dental caries frequency of skeletal remains. HOMO 54(1):57-70.

Eaton BS, Eaton III SB, Cordain L. 2002. Evolution, diet, and health. In: Ungar PS, Teaford MF, editors. Human diet: Its origins and evolution. Westport, CT: Bergin and Garvey. p 7-18.

Edwards DN. 1998. Gabati: A Meroitic, post-Meroitic and medieval cemetery in central Sudan. Volume 1. London: Sudan Archaeological Research Society.

El-Najjar M, Desanti MV, Ozebek L. 1978. Prevalence and possible etiology of dental enamel hypoplasia. American Journal of Physical Anthropology 48:185-192.

Erdal YS, Duyar I. 1999. Brief communication: A new correction procedure for calibrating dental caries frequency. American Journal of Physical Anthropology 108:237-240.

Eshed V, Gopher A, Hershkovitz I. 2006. Tooth wear and dental pathology at the advent of agriculture: New evidence from the Levant. American Journal of Physical Anthropology 130: 145-159.

Fahmy AG. 2000. What they ate: Plant remains from HK43. Nekhen News 12:19.

Fairgrieve SI, Molto JE. 2000. Cribra orbitalia in two temporally disjunct population samples from the Dakleh Oasis, Egypt. American Journal of Physical Anthropology 111:319-331.

Field A. 2009. Discovering Statistics Using SPSS, Third Edition. Sage Publications.

Firestone AR, Schmid R, Muhlemann HR. 1984. Effect of the length and number of intervals between meals on caries in rats. Caries Research 18:128-133.

Flannery KV. 1973. The origins of agriculture. Annual Review of Anthropology 2:271-310.

Forshaw RJ. 2009. Dental health and disease in ancient Egypt. British Dental Journal 206 (8):421-424.

Friedman R. 2006. Excavating Egypt's early kings: Recent discoveries in the elite cemetery at Hierankopolis. In: Egypt at its Origins 2: Proceedings of the International Conference 'Origin of the State, Predynastic and Dynastic Egypt'. Toulouse, France. p 1157-1194.

Friedman R. 2007. The Nubian cemetery at Hirankopolis, Egypt. Results of the 2007 season. Sudan and Nubia.

Friedman R. 2008. The cemeteries of Hierankopolis. Archeo-Nil 18:9-29.

Fuentes A. 2010. The New Biological Anthropology: Bringing Washburn's New Physical Anthropology into 2010 and beyond—the 2008 AAPA luncheon lecture. Yearbook of Physical Anthropology 53:2-12.

Fuller DQ. 2004. Early Kushite agriculture: Archaeobotanical evidence from Kawa. Sudan and Nubia 8:70-74. London: SARS.

Garn SM, Lewis AB, Kerewsky RS. 1966. Sexual dimorphism in the buccolingual tooth diameter. Journal of Dental Research 45:1819.

Gatto MC. 1997. Regional variations in the so-called "A-Group" culture of Lower Nubia. In: Barich B, and Gatto MC, editors. Dynamics of Populations, Movements, and Responses to Climactic Change in Africa. Rome: Bonsigniori Editore. p 105-111.

Gautier A. 1984. Archaeozoology of the Bir Kiseiba region, eastern Sahara. In: Wendorf F, Schild R, Close AE, editors. Cattle Keepers of the Eastern Sahara. Dallas: Southern Methodist University Press. p 49-72.

Geller J. 1992. From prehistory to history: Beer in Egypt. In: Friedman R, Adams B, editors. The Followers of Horus: Studies Dedicated to Michael Hoffman 1944-1990. Oxford:Oxbow. p 19-26.

Geus F. 1991. Burial customs in the Upper Main Nile: An overview. In: Davies WV, editor. Egypt and Africa. Nubia from Prehistory to Islam. London: British Museum Press. p 57-73.

Gifford-Gonzalez D. 2013. Animal genetics and African archaeology: Why it matters. African Archaeological Review 30:1-20.

Goodman AH, Armelagos GJ, Rose JC. 1984. The chronological distribution of enamel hypoplasias from prehistoric Dickson Mounds populations. American Journal of Physical Anthropology 65:259-266.

Goodman AH, Rose JC. 1990. Assessment of systematic physiological perturbations from dental enamel hypoplasias and associated histological structures. Yearbook of Physical Anthropolology 39:59-110.

Grajetzki W. 2008. The architecture and the signification of the Tarkhan mastabas. Archaeo-Nil 18:103-112.

Gravetter FJ, Wallnau LB. 2008. Essentials of Statistics for the Behavioral Sciences, Sixth Edition. Thomson Wadsworth.

Greene DL. 1972. Dental anthropology of early Egypt and Nubia. Journal of Human Evolution 3:315-324.

Greene DL, Ewing GH, Armelagos GJ. 1967. Dentition of a Mesolithic population from Wadi Halfa, Sudan. American Journal of Physical Anthropology 27:41-56.

Greene TR. 2006. Diet and dental health in Predynastic Egypt: A comparison of Hierankopolis and Naqada. PhD dissertation. Anthropology Department, University of Alaska Fairbanks.

Grilletto R. 1973. Caries and dental attrition in the early Egyptians as seen in the Turin Collections. In: Brothwell DR, Chiarelli BA, editors. Population Biology of Ancient Egyptians. NY: Academic Press. p 325-331.

Grine FE. 1986. Dental evidence for dietary differences in *Austraopithecus* and *Paranthropus*: A quantitative analysis of permanent molar microwear. Journal of Human Evolution 15:783-822.

Guatelli-Steinberg D. 2008. Using perikymata to estimate the duration of growth disruptions in fossil homini teeth: Issues of methodology and interpretation. In: Irish JD, Nelson GC, editors. Technique and application in dental anthropology. Cambridge University Press. p 71-85.

Gustafsson BE, Quensel CE, Lanke LS, Lunqvist C, Grahnen H, Bonow EB, Krasse B. 1954. The Vipeholm dental caries study: the effect of different levels of carbohydrate intake on caries activity in 436 individuals. Acta Odontologica Scandinavica 11:232-364.

Haaland R. 1977. Archaeological classification and ethnic groups: A case study from Sudanese Nubia. Norwegian Archaeological Review 10(1-2):1-31.

Haaland R. 1981. Seasonality and division of labor: A case study from Neolithic sites in the Khartoum Nile environment. Norwegian Archaeological Review 14(1):44-59.

Haaland R, Magid AA. 1992. Mesolithic sites in the Atbara region. Nubian Letters 18:4-13.

Hafsaas-Tsakos H. 2009. The kingdom of Kush: An African centre in the periphery of the Bronze Age world system. Norwegian Archaeological Review 42(1):50-70.

Haldane JBS. 1949. Disease and evolution. Supplement to La Ricerca Scientifica 19:68-76.

Hanihara T, Ishida H. 2005. Metric dental variation of major human populations. American Journal of Physical Anthropology 128:287-298.

Harris EF, Bailit HL. 1980. The metaconule: A morphologic and familial analysis of a molar cusp in humans. American Journal of Physical Anthropology 53:349-358.

Harris JE, Ponitz PV. 1983. Dental health in ancient Egypt. In: Cockburn A, Cockburn E, editors. Mummies, disease, and ancient cultures. Cambridge University Press. p 45-51.

Hartnady P, Rose JC. 1991. Abnormal tooth loss among Archaic period inhabitants of the Lower Pecos region, Texas. In: Kelley MA, Larsen CS, editors. Advances in Dental Anthropology. New York:Wiley-Liss. p 267-278.

Hassan FA. 1978. Archaeological explorations of the Siwa Oasis region, Egypt. Current Anthropology 19(1):146-148.

Hassan FA. 1980. Prehistoric settlements along the main Nile. In: Williams MAJ, Faure H, editors. The Sahara and the Nile. Rotterdam: AA Balkema. p 421-450.

Hassan FA. 1984. Towards a model of agricultural development in Predynastic Egypt. In: Krzyzaniak Lech, Kobusiewitz Michal, editors. Origin and Development of Food Producing Cultures in North-East Africa. Poznan: Poznan Archaeological Museum. p 221-224.

Hassan FA. 1986. Desert environment and the origins of agriculture in Egypt. Norwegian Archaeological Review 19(2):63-76.

Hassan FA. 1988. The Predyanstic of Egypt. Journal of World Archaeology 2:135-185.

Hassan FA. 1997a. Egypt: Beginnings of agriculture. In: Vogel JO, editor. Encyclopedia of Precolonial Africa: Archaeology, History, Languages, Cultures and Environment. Walnut Creek: Alta Mira Press. p 405-409.

Hassan FA. 1997b. Egypt: Emergence of state society. In: Vogel JO, editor. Encyclopedia of Precolonial Africa: Archaeology, History, Languages, Cultures and Environment. Walnut Creek, CA: Alta Mira Press. p 472-479.

Hassan FA. 1997c. The dynamics of a riverine civilization: A geoarchaeological perspective on the Nile Valley, Egypt. World Archaeology 29(1):51-74.

Hassan FA. 2000. Climate and cattle in north Africa: A first approximation. In: Blench R, McDonald KC, editors. The Origins and Development of African Livestock. Archaeology, Genetics, Linguistics, and Ethnography. University College London. p 61-86.

Hayes WC. 1969. Most ancient Egypt: Chapter III. The Neolithic and Chalcolithic communities of northern Egypt. Journal of Near Eastern Studies 23(4):217-272.

Hays TR. 1984. Predynastic development in Upper Egypt. In: Krzyzaniak L, and Kobusiewitz M, editors. Origin and Early Development of Food Producing Cultures in NE Africa. Poznan Archaeological Museum. p 211-219.

Hendrickx S, Vermeersch P. 2000. Prehistory: From the Paleolithic to the Badarian culture (c. 700,000 – 4,000 BC). In: Shaw Ian, editor. The Oxford History of Ancient Egypt. Cambridge University Press. p 17-43.

Hildebolt CF, Elvin-Lewis M, Molnar S, McKee JK, Perkins MD, Young KL. 1989. Caries prevalence among geochemical regions of Missouri. American Journal of Physical Anthropology 78:79-92.

Hillson S. 1979. Diet and dental disease. World Archaeology 11(2), Food and Nutrition. p 147-162.

Hillson S. 1996. Dental Anthropology. Cambridge University Press.

Hillson S. 2000. Dental pathology. In: Katzenberg AM, Saunders SR, editors. Biological Anthropology of the Human Dkeleton. Wiley-Liss, Inc. p 249-286.

Hillson S. 2001. Recording dental carries in archaeological human remains. International Journal of Osteoarchaeology 11:249-289.

Hillson S. 2005. Teeth, second edition. Cambridge University Press.

Hillson S. 2008. The current state of dental decay. In: Irish JD, Nelson GC, editors. Technique and application in dental anthropology. Cambridge University Press. p 111-134.

Hillson S, Bond S. 1997. Relationship of enamel hypoplasia to the pattern of tooth crown growth: A discussion. American Journal of Physical Anthropology 104:89-103.

Hinton RJ. 1982. Differences in interproximal and occlusal tooth wear among prehistoric Tennessee Indians: Implications and masticatory function. American Journal of Physical Anthropology 57:103-115.

Hinton PR. 2004. Statistics Explained, second edition. Routledge.

Hoffman MA, Hamroush HA, Allen RO. 1986. A model of urban development from the Hierankopolis region from Predynastic through Old Kingdom times. Journal of the American Research Center in Egypt 23:175-187.

Howell C. 1995. Fundamental Statistics for the Behavioral Sciences. Duxbury Press.

Hummert J, Van Gerven DP. 1982. Tetracycline-labeled human bone from a medieval population in Nubia's Batn el Hajar (550-1450 AD). Human Biology 54(2):355-371.

Iacumin P. 2008. Cemetery R12: An isotope approach. In: Salvatori S, Usai D, editors. A Neolithic Cemetery in The Northern Dongola Reach (Sudan): Excavations at Site R12. London:SARS.

Iacumin P, Bocherens H, Mariotti A, Longinelli A. 1996. An isotopic paleoenviromental study of human skeletal remains from the Nile Valley. Paleogeography, Paleoclimatology, Paleoecology. 126:15-30.

Iacumin P, Bocherens H, Chaix L, Marioth A. 1998. Stable carbon and nitrogen isotopes as dietary indicators of ancient Nubian populations. Journal of Archaeological Science 25:293-301.

Ibrahim MA. 1987. A study of dental attrition and diet in some ancient Egyptian populations. PhD dissertation. Department of Anthropology, Durham University.

Inhorn MC, Brown P. 1990. The anthropology of infectious disease. Annual Review of Anthropology 19:89-117.

Irish JD. 1998a. Ancestral dental traits in recent sub-Saharan Africans and the origins of modern humans. Journal of Human Evolution 34:81-98.

Irish JD. 1998b. Dental morphological indications of population discontinuity and Egyptian gene flow in post-Paleolithic Nubia. In: Lukacs JR, editor. Human dental development, morphology, and pathology: A tribute to Albert A. Dahlberg. University of Oregon Anthropological Papers no.54:155-172.

Irish JD. 2000. The Iberomaurusian enigma: North African progenitor or dead end? Journal of Human Evolution 39:393-410.

Irish JD. 2005. Population continuity vs. discontinuity revisited: Dental affinities among Late Paleolithic through Christian era Nubians. American Journal of Physical Anthropology 128:520-535.

Irish JD. 2006. Who were the ancient Egyptians? Dental affinities among Neolithic through postdynastic peoples. American Journal of Physical Anthropology 129:529-543.

Irish JD. 2008. A dental assessment of biological affinity between inhabitants of the Gebel Ramlah and R12 Neolithic sites. In: Sulgostowska Z, Tomaszewski AJ, editors. Studies in Honor of Romuald Schild. Warsaw: Polish Academy of Sciences.

Irish JD, Hemphill BE. 2004. An odontometric investigation of Canary Islander origins. Dental Anthropology 17(1):8-17.

Irish JD, Konigsberg L. 2007. The ancient inhabitants of Jebel Moya redux: Measures of population affinity based on dental morphology. International Journal of Osteoarchaeology 17:138-156.

Irish JD, Friedman R. 2010. Dental affinities of the C-Group inhabitants of Hierankopolis, Egypt: Nubian, Egyptian, or both? HOMO 61:81-101.

Irish JD, Guatelli-Steinberg D, Legge SS, De Ruiter DJ, Berger LR. 2013. Dental morphology and the phylogenetic “place” of Australopithecus sediba. Science 340.

Johnson AL, Lovell NC. 1994. Biological differentiation at Predynastic Naqada, Egypt: An analysis of dental morphological traits. American Journal of Physical Anthropology 93:427-433.

Johnson AL, Lovell NC. 1995. Dental morphological evidence for biological continuity between the A-Group and C-Group periods in Lower Nubia. International Journal of Osteoarchaeology 5:368-376.

Johansson I, Larsson B, Nordlund A, Erickson T. 1994. Diet and dental caries. American Journal of Clinical Nutrition 59:788S.

Judd MA. 2004. Trauma in the city of Kerma: Ancient versus modern injury patterns. International Journal of Osteoarchaeology 14:34-51.

Judd MA. 2008. The human skeletal analysis. In: Salvatori S, Usai D, editors. A Neolithic Cemetery In the Northern Dongola Reach (Sudan): Excavations at Site R12. London:SARS. p 83-104.

Katzenberg MA. 2000. Stable isotope analysis: A tool for studying past diet, demography, and life history. In: Katzenberg MA, Saunders SR, editors. Biological Anthropology of the Human Skeleton. p 305-327.

Kedjarune U, Migasena P, Changbumrung S, Pongpaew P, Tungtongchitr R. 1997. Flow rate and composition of whole saliva in children from rural and urban Thailand with different caries prevalence and dietary intake. Caries Research 31:148-54.

Kelley MA, Levesque DR, Weidl E. 1991. Contrastin patterns of dental disease in five early northern Chilean groups. In: Kelley MA, Larsen CS, editors. Advances in Dental Anthropology. New York:Wiley-Liss. p 203-213.

Kemp BJ. 1994. Food for an Egyptian city: Tell el Amarna. In: Luff R, Rowley-Conwy P, editors. Whither Environmental Archaeology? Oxford: Oxbow Books. p 133-153.

Kerr NW, Bruce MF, Cross JF. 1988. Caries experience in the permanent dentition of Late Medieval Scots (1300-1600 AD). Archives of Oral Biology 33(3):143-148.

Kerr NW, Bruce MF, Cross JF. 1990. Caries experience in Medieval Scots. American Journal of Physical Anthropology 83:69-76.

Kinnear PR, Gray CD. 2010. PASW 17 Statistics Made Simple. Psychology Press.

Kloos H, David R. 2002. The paleoepidemiology of schistosomiasis in ancient Egypt. Human Ecology Review 9(1):14-25.

Kobusiewicz M, Kabasinski J, Schild R, Irish JD, Wendorf F. 2004. Discovery of the first Neolithic cemetery in Egypt's western desert. Antiquity 78:566-578.

Koritzer RT. 1968. An analysis of the cause of tooth loss in an ancient Egyptian population. American Anthropologist 70:550-553.

Koritzer RT. 1977. An anthropological approach to the study of dental pathology. In: Dahlberg AA, Graber TM, editors. Orofacial Growth and Development. The Hague:Moule Publishers. p 283-299.

Knutson I. 1975. Dental pathology of human remains from an archaic site in southern Saskatchewan. MA thesis. Anthropology Department, University of Manitoba.

Krzyzaniak L. 1991. Early farming in the middle Nile basin: Recent discoveries at Kadero (Central Sudan). Antiquity 65:515-532.

Kuper R, Kröpelin S. 2006. Climate-controlled Holocene occupation in the Sahara: Motor of Africa's evolution. Science 313:803-807.

Lafranco LP, Eggers S. 2010. The usefulness of caries frequency depth, and location in determining cariogenicity and past subsistence: A test on early and later agriculturalists from the Peruvian Coast. Amrican Journal of Physical Anthropology 142:75-91.

Larsen CS. 1996. Biological changes in buman populations with agriculture. Annual Review of Anthropology 24:185-213.

Larsen CS.1997. Bioarchaeology: Interpreting Behavior from The Human Skeleton. Cambridge University Press.

Larsen CS. 2002. Bioarchaeology: The Lives and lifestyles of past peoples. Journal of Archaeological Research 10(2):119-166.

Larsen CS. 2006. The agricultural revolution as environmental catastrophe: implications for health and lifestyle in the Holocene. Quaternary International 150:12-20.

Larsen CS, Shavit R, Griffin MC. 1991. Dental caries evidence for dietary change: An archaeological context. In: Kelley MA, Larsen CS, editors. Advances in Dental Anthropology. Wiley-Lis, Inc.

Larsen CS, Crosby AW, Griffin MC, Hutchinson DL, Ruff CB, Russell KF, Schoeninger MJ, Sering LE, Simpson SW, Talacs JL, Teaford MF. 2002. A biohistory of health and behavior in the Georgia Bight. The agricultural transition and the impact of European contact. In: Steckel RH, Rose JC, editors. The backbone of history: Health and nutrition in the western hemisphere. Cambridge University Press. p 406-439.

Larsen CS, Hutchinson DL, Stojanowski CM, Williamson MA, Griffin MC, Simpson SW, Ruff CB, Schoeninger MJ, Norr L, Teaford MF, Driscoll EM, Schmidt CW, Tung TA. 2007. Health and lifestyle in Georgia and Florida. Agricultural origins and intensification in regional perspective. In: Cohen MN, Crane-Kramer MM, editors. Ancient Health. University Press of Florida. p 20-34.

Leek FF. 1966. Observations on the dental pathology seen in ancient Egyptians. The Journal of Egyptian Archaeology 52: 59-64

Leek FF. 1972a. Bite, attrition and associated oral conditions as seen in ancient Egyptian skulls. Journal of Human Evolution 1: 289-295.

Leek FF. 1972b. Teeth and bread in ancient Egypt. The Journal of Egyptian Archaeology 58: 126-132.

Leigh RW. 1925. Dental pathology of Indian tribes of varied environmental and food conditions. Am J Phys Anthrop 13(2):179-199.

Legler DW, Menaker L. 1980. Definition, etiology, epidemiology, and clinical implication of dental caries. In: Menaker L, editor. The biological basis of dental caries. New York: Harper and Row. p 217.

Leverett DH. 1982. Fluorides and the changing prevalence of caries. Science 217:26-30.

Lingstrom P, Van Houte J, Kashket S. 2000. Food starches and dental caries. Critical Reviews in Oral Biology and Medicine 11(3):366-380.

Linseele V. 2010. Did specialized pastoralism develop differently in Africa than in the Near East? Journal of World Prehistory 23(2):43-77.

Linstädter J, Kröpelin S. 2004. Wadi Bakht re-visited: Holocene climate change and prehistoric occupation of the eastern Sahara, SW Egypt. Geoarchaeology 19(8):753-778.

Lloyd AB. 2000. The Ptolemaic period (c. 332-30 BC). In: Shaw, Ian, editor. The Oxford History of Ancient Egypt. Oxford University Press. p 388-413.

Lubell D, Jackes M, Schwarz H, Knyf M, Meiklejohn C. 1994. The Mesolithic-Neolithic transition in Portugal: Isotopic and dental evidence of diet. Journal of Archaeological Science 21:201-216.

Lukacs JR. 1989. Dental paleopathology: Methods for reconstructing dietary patterns. In: Iscan MY, Kennedy AR, editors. Reconstruction of life from the skeleton. Wiley-Liss. p 261-286.

Lukacs JR.1992. Dental paleopathology and agricultural intensification in South Asia: New evidence from Bronze Age Harappa. American Journal of Physical Anthropology 87: 133-150.

Lukacs JR. 1995. The 'caries correction factor': A new method of calibrating dental caries rates to compensate for antemortem tooth loss. International Journal of Osteoarchaeology 5:151-156.

Lukacs JR. 1996. Sex differences in dental caries with the origin of agriculture in south Asia. Current Anthropology 37(1): 147-153.

Lukacs JR. 2008. Fertility and agriculture accentuate sex differences in dental caries rates. Current Anthropology 49(5):901-914.

Lukacs JR, Hemphill BE. 1993. Odontometry and biological affinity in south Asia: Analysis of three ethnic groups from northern India. Human Biology 65(2): 279-325.

Lukacs JR, Largaespada LL. 2006. Explaining sex differences in dental caries prevalence: Saliva, hormones, and "life-history" etiologies. American Journal of Human Biology 18: 540-555.

Lukacs JR, Thompson LM. 2008. Dental caries prevalence by sex in prehistory: magnitude and meaning. In: Irish JD, Nelson GC, editors. Technique and application in dental anthropology. Cambridge University Press. p 136-170.

Lunt DA. 1974. The prevalence of dental caries in the permanent dentition of Scottish prehistoric and medieval populations. Archs Oral Biol 19: 431-437.

Madrigal L. 1998. Statistics for Anthropology. Cambridge University Press.

Malek J. 2000. The Old Kingdom (c. 2686-2160 bC). In: Shaw I, editor. The Oxford History of Ancient Egypt. Oxford University Press. p 83-107.

Mandel ID. 1970. Effects of dietary modifications on caries in humans. Journal of Dental Research 49:1201-1211.

Manji F, Fejerskov O, Baelum V. 1989. Pattern of dental disease in ana adult rural population. Caries Research 23:55-62.

Manji F, Fejerskov O, Baelum V, Luan WM, Chen X. 1991. The epidemiological features of dental caries in African and Chinese populations: Implications for risk assessment. In: Johnson NW, editor. Dental Caries: Markers of High and Low Risk Groups and Individuals. Cambridge University Press. p 62-99.

Mansbridge JN. 1959. Sex differences in the prevalence of dental caries. British Dental Journal 106:303-308.

Marks AE. 1991. Relationships between the central Nile Valley and the eastern Sudan in late prehistory. In: Davies WV, editor. Egypt and Africa. Nubia from Prehistory to Islam. British Museum Press. p 30-39.

Martin DL, Armelagos GJ, Goodman AH, Van Gerven DP. 1984. The effects of socio--economic change in prehistoric Africa: Sudanese Nubia as a case study. In: Cohen MN, Armelagos GJ, editors. Paleopathology at the Origins of Agriculture. Orlando:Academic Press.

Matovich J. 2002. Health in Predynastic Egypt: Using skeletal stress indicators to assess the overall health of a working class population in Hierankopolis. MA thesis. Anthropology Department, University of Alaska Fairbanks.

Matthesen M, Baelum V, Aarslev I, Fejerskov O. 1990. Dental health of children and adults in Guinea-Bissau, west Africa, in 1986. Community Dental Health 7:123-133.

Mayhall JT. 1970. The effect of culture change upon the Eskimo dentition. Arctic Anthropology 7:117-121.

Meiklejohn C, Baldwin JH, Schentag CT. 1988. Caries as a probable dietary marker in the western European Mesolithic. In: Kennedy BV, LeMoine GM, editors. Diet and Subsistence: Current Archaeological Perspectives. Proceedings of the Nineteenth Annual Conference of the University of Calgary. Calgary, Alberta: University of Calgary Press. p 273-279.

Meskell LM. 2000. Writing the body in archaeology. In: Rautman AE, editor. Reading the Body. Representations and Remains in the Archaeological Record. Philadelphia:University of Pennsylvania Press. p 13-21.

Michalek SM, McGhee JR, Shiota T. 1977. Virulence of Streptococcus mutans: Cariogenicity of S. mutans in adult gnotobiotic rats. Infect Immun 15:466.

Midant-Reynes B. 2000. The Naqada period (c. 4,000-3,200 BC). In Shaw I, editor. The Oxford History of Ancient Egypt. Cambridge University Press. p 41-56.

Milner GR. 1984. Dental caries in the permanent dentition of a Mississippian period population from the American Midwest. Collegium Anthropologicum 8:77-91.

Molnar S, Barrett MJ, Brian L, Brace LC, Brose DS, Dewy JR, Frisch JE, Ganguly P, Gejvall NG, Greene DL, Kennedy K, Poirier FE, Pourchet MJ, Rhine S, Turner II CG, Van Valen L, Von Koenigswald GHR, Wilkinson RG. 1972. Tooth wear and culture: A survey of tooth functions among some prehistoric populations. Current Anthropology 13(5):511-526.

Molnar S, Molnar I. 1985. Observations of dental diseases among prehistoric populations of Hungary. American Journal of Physical Anthropology 67:51-63.

Moodie RL. 1923. Paleopathology. Chicago: University of Illinois Press.

Moodie RL. 1948. A history of dentistry, second edition. Philadelphia: Lea and Febiger.

Moore WJ, Corbett ME. 1971. Distribution of dental caries in ancient British populations I Anglo-Saxon Period. Caries Research 5:151-168.

Morcos SR, Morcos WR. 1977. Diets in ancient Egypt. Progress in Food and Nutrition Science 2:457-471.

Morkot RG. 1991. Nubia in the New Kingdom: The limits of Egyptian control. In: Davies WV, editor. Egypt and Africa. Nubia from Prehistory to Islam. British Museum Press. p 294-301.

Morkot RG. 2001. Egypt in Nubia. In: Alcock SE, D'Altroy TN, Morrison K, Sinopoli SM, editors. Empires: Perspectives from Archaeology and History. Cambridge University Press. p 227-251.

Mormann JE, Muhlemann HR. 1981. Oral starch degradation and its influence on acid production on human dental plaque. Caries Research 15:166-175.

Mummery J. 1870. On the relations which dental caries, as discovered among the ancient inhabitants of Britain, and amongst existing aboriginal races, may be supposed to hold to their food and social custom. Transactions of the Odontological Society of Great Britain 2. p 2-102.

Murray MA. 2000. Cereal production and processing. In: Nicholson PT, Shaw I, editors. Ancient Egyptian Materials and Technology. Cambridge: Cambridge University Press. p 505-536.

Navia JM. 1994. Carbohydrates and dental health. American Journal of Clinical Nutrition 59 (suppl):719S-727S.

Nelson GC, Lukacs JR, Yule P. 1999. Dates, caries, and early tooth loss during the Iron Age of Oman. American Journal of Physical Anthropology 108:333-343.

Nelson ML, Dinardo A, Hochberg J, Armelagos GJ. 2010. Brief communication: Mass spectroscopic characterization of tetracycline in the skeletal remains of an ancient population from Sudanese Nubia 350-550 CE. American Journal of Physical Anthropology 143:151-154.

Newbrun. 1982. Sugar and dental caries: A review of human studies. Science 217:418-423.

Norušis MJ. 2010. PASW Statistics 18 Guide to Data Analysis. Prentice Hall.

O'Connor D. 1991. Early states along the Nubian Nile. In: Davies W, editor. Egypt and Africa. Nubia from Prehistory to Islam. British Museum Press. p 145-165.

Ozturk A, Famili P, Vieira AR. 2010. The antimicrobial peptide DEFB1 is associated with caries. Journal of Dental Research 89(6):631-636.

Pain S. 2005. Why the Pharaohs never smiled. New Scientist, 2 July 2005:36-39.

Palmer CA, Kent Jr. R, Loo CY, Hughes CV, Stutius E, Pradhan N, Dahlan M, Kanasi E, Arevalo Vasquez SS, Tanner ACR. 2010. Diet and caries-associated bacteria in severe early childhood caries. Journal of Dental Research 89(11):1224-1229.

Palmieri AM. 1983. Dietary significance of bone strontium in ancient Sudanese adaptations. In: Pottery Using Hunters and Gatherers at Saggai (Sudan); Preconditions for Food Production, Vol. 12. p 140-148.

Papathanasiou A. 2001. A bioarchaeological analysis of Neolithic Alepotrypa Cave, Greece. BAR International Reports 961.

Papathanasiou A. 2005. Health status of the Neolithic population of Alepotrypa Cave, Greece. American Journal of Physical Anthropology 126:377-390.

Papathanasiou A, Zachou E, Richards MP. 2009. Bioarchaeological analysis of the human osteological material from Proskynas, Lokris. Hesperia Supplements 43: New Directions in the Skeletal Biology of Greece. Athens, Greece: The American School of Classical Studies at Athens.

Patch DC. 2004. Settlement patterns and culture change in the Predynastic period. In: Hendrickx S, Friedman RF, Cialowitz KM, Chlodnicki M, editors. Egypt at Its Origins: Studies in Memory of Barbara Adams. Proceedings of the International Conference ‘Origin of the State, Predynastic, and Early Dynastic Egypt’. Krakow 28th August-1st September 2002. Leuven: Peeters. p 905-918.

Parker PM. 2003. Food, identity, and culture: An introduction and overview. In: Pearson MP, editor. Food, Culture, and Identity in the Neolithic and early Bronze Age. Oxford: Archaeopress. p 1-30.

Peacock D. 2000. The Roman Period (30 BC-AD 395). In: Shaw Ian, editor. The Oxford History of Ancient Egypt. Cambridge Univeristy Press. p 414-436.

Peressinotto D, Schmitt A, Lecointe Y, Pouriel R, Geus F. 2004. Neolithic nomads at El Multaga, Upper Nubia, Sudan. Antiquity 78:54-60

Peters J. 1991. Mesolithic fishing along the central Sudanese Nile and Lower Atbara. Sahara: Prehistory and History of the Sahara 4:33-40.

Peters J. 1993. Animal exploitation between the Fifth and Sixth Cataract ca. 8,500-7,000 BP: A preliminary report on the faunas from El Damer, Abu Darbein, and Aneibis. In: Krzyzaniak L, Kobusiewitz M, Alexander J, editors. Environmental Change and Human Culture in the Nile Basin and Northern Africa Untill the Second Millenium BC. Poznan Archaeological Museum. p 413-419.

Petersen PE, Lennon MA. 2004. Effective use of fluorides for the prevention of dental caries in the 21st century: the WHO approach. Community Dentistry and Oral Epidemiology 32: 319-321.

Poole F. 1999. Elephantine. In: Bard Kathryn A, editor. Encyclopedia of The Archaeology of Ancient Egypt. Routledge.

Powell ML. 1985. The analysis of dental wear and caries for diet reconstruction. In: Gilbert RI, Mielke JH, editors. The Analysis of Prehistoric Diets. New York: Academic Press. p 307-338.

Puech PF, Serratrice C, Leek FF. 1983. Tooth wear as observed in ancient Egyptian skulls. Journal of Human Evolution 12:617-629.

Ritzman TB, Baker BJ, Schwartz GT. 2008. A fine line: A comparison of methods for estimating ages of linear enamel hypoplasia formation. American Journal of Physical Anthropology 135: 348-361.

Rose JC, Condon KW, Goodman AH. 1985. Diet and dentition: Developmental disturbances. In: Gilbert RI, Mielke JH, editors. The Analysis of Prehistoric Diets. Academic Press. p 281-306.

Rose JC, Armelagos GJ, Perry LS. 1993. Dental anthropology of the Nile Valley. In: Biological anthropology and the study of ancient Egypt. p 61-74.

Rudney JD, Chen R, Zhang G. 2005. Streptococci dominate the diverse flora within buccal cells. Journal of Dental Research 84(12):1165-1171.

Ruffer A. 1920. Study of abnormality and pathology of ancient Egyptian teeth. American Journal of Physical Anthropology 3(3): 335-390.

Saffirio L. 1972. Food and dietary habits in ancient Egypt. Journal of Human Evolution 1: 297- 305.

Salvatori S, Usai D. 2001. First season of excavation at the R12 Late Neolithic cemetery in the northern Dongola Reach (Kawa, Sudan): Preliminary report. Rivista di Archaeologia, Anno XXV. Roma.

Salvatori S, Usai D. 2002. The second excavation season at R12, a Late Neolithic cemetery in the northern Dongola Reach. Sudan and Nubia 6:2-7.

Salvatori S, Usai D. 2008. Introduction. In: Salvatori S, Usai D, editors. A Neolithic Cemetery in the Northern Dongola Reach (Sudan): Excavations at Site R12. London: SARS.

Samuel D. 2000. Brewing and baking. In: Nicholson PT, Shaw I, editors. Ancient Egyptian Materials and Technology. Cambridge: Cambridge University Press. p 537-576.

Satinoff MI. 1972. The medical biology of the early Egyptian populations from Asswan, Asyut and Gebelen. Journal of Human Evolution 1:247-257.

Saunders SR, De Vito C, KM. 1997. Dental caries in nineteenth century Upper Canada. American Journal of Physical Anthropology 104:71-87.

Schell LM. 1997. Culture as stressor: A revised model of biocultural interaction. American Journal of Physical Anthropology 102:66-77.

Schild R, Kobusiewitz M, Wendorf F, Kabacinski J, Irish JD, Krolik H, Calderoni G. 2005. A new important area of Neolithic occupation in the southwestern desert of Egypt. In: Barich BE, Striedter KH, editors. Hunters vs. Pastoralists in the Sahara; Material Culture and Symbolic Aspects. Oxbow Books. p 51-56.

Schillaci MA, Irish JD, Wood CE. 2009. Further analysis of the population history of ancient Egyptians. American Journal of Physical Anthropology 139:235-243.

Schmid R, Cleaton-Jones P, Lutz F. 1988. Cariogenicity of traditional African foodstuffs (maize, beans, sorghum, brown bread) on rat caries. Caries Research 22:242-245.

Schneider KN. 1986. Dental caries, enamel composition, and subsistence among prehistoric Amerindians of Ohio. American Journal of Physical Anthropology 71: 95- 102.

Schoeninger MJ. 1979. Diet and status at Chalcatzingo: Some empirical and technical aspects of strontium analysis. American Journal of Physical Anthropology 51:295-310.

Schollmeyer KG, Turner II CG. 2004. Dental caries, prehistoric diet, and the pithouse-to-pueblo transition in southern Colorado. American Antiquity 69(3):569-582.

Schwarcz HP, Schoeninger MJ. 1991. Stable isotope analysis in human nutritional ecology. Yearbook of Physical Anthropology 34: 283-321.

Schwartz A, Weisberger D. 1955. Salivary factors in experimental animal caries. In: Sognnaes RF, editor. Advances in Experimental Caries Research. p 125.

Scott RG, Turner II G. 1988. Dental Anthropology. Annual Review of Anthropology 17:99-126.

Scott RG. 1991. Dental anthropology. In: Encyclopedia of Human Biology, Vol. 2. Academic Press.

Screebny LM. 1983. Cereal availability and dental caries. Community Dentistry and Oral Epidemiology 11:148-155.

Sealy JC, Patrick MK, Morris AG, Alder D. 1992. Diet and dental caries among later Stone Age inhabitants of the Cape Province, South Africa. American Journal of Physical Anthropology 88:123-134.

Seidlmayer S. 2000. The First Intermediate Period (c. 2160-2055 BC). In: Shaw I, editor. The Oxford History of Ancient Egypt. Oxford University Press. p 108-136.

Selwitz RH, Ismail AI, Pitts NB. 2007. Dental caries. Lancet 369:51-59.

Shaw I. 2000. Egypt and the outside world. In: Shaw Ian, editor. The Oxford History of Ancient Egypt. p 308-323.

Sheiham A. 1983. Sugars and dental decay. The Lancet. February 5th:82-284.

Sheiham A. 2006. Dental caries affects body weight, growth and quality of life in pre-school children. British Dental Journal 201(10):625-626.

Sillen A, Kavanagh M. 1982. Strontium and paleodietary research: A review. Yearbook of Physical Anthropology 25:67-90.

Smith AB. 1984a. Origins of the Neolithic in the Sahara. In: Rothenberg B, Brandt SA, editors. From Hunters to Farmers: The Causes and Consequences of Food Production in Africa. Berkeley, CA. p 84-92.

Smith HB. 1984b. Patterns of molar wear in hunter-gatherers and agriculturalists. American Journal of Physical Anthropology 63:39-66.

Smith NJD. 1986. Dental pathology in an ancient Egyptian population. In: David RA, editor. Science in Egyptology. Manchester, UK: Manchester University Press. p 43-48.

Smith HS. 1991. The development of the ‘A-Group’ culture in northern Lower Nubia. In: Davies W, editor. Egypt and Africa. Nubia from Prehistory to Islam. British Museum Press. p 92-111.

Smith STyson. 1998. Nubia and Egypt: Interaction, acculturation, and secondary state formation from the Third to First Millennium BC. In: Cusick JG, editor. Studies in Culture Contact: Interaction, Culture Change, and Archaeology. Carbondale:Southern Illinois University. p 256-287.

Smith P, Bar-Yosef O, Sillen A. 1984. Archaeological and skeletal evidence for dieatary change during the Late Pleistocene/Early Holocene in the Levant. In: Cohen MN, Armelagos JG. Paleopathology at the origins of agriculture. New York: Academic Press.

Steckel RH, Rose JC, Larsen CS, Walker Phillip L. 2002. Skeletal health in the western hemisphere from 4000 BC to the present. Evolutionary Anthropology 11:142-155

Stewart, TD. 1931. Dental caries in Peruvian skulls. Am J Phys Anthrop 15(2):315-326.

Stock F, Gifford-Gonzalez D. 2013. Genetics and African cattle domestication. African Archaeological Review 30:51-72.

Streckfus CE, Baur U, Brown JL, Bacal C, Metter, Todd N. 1998. Effect of estrogen status and aging on salivary flow rates in healthy Caucasian women. Gerontology 44:32-39.

Street AF, Grove AT. 1976. Environmental and climatic implications of late Quaternary lake level fluctuations in Africa. Nature 261:385-390.

Swanson CE. 1976. Dental pathologies in Gran Quivira. Master's thesis. Anthropology Department, Arizona State University.

Sullivan R. 1995. A brief journey into medical care and disease in ancient Egypt. Journal of the Royal Society of Medicine 88:141-145.

Tabachnick BG, Fidell LS. 2006. Using Multivariate Statistics, fifth edition. Pearson.

Takeuchi M. 1962. On the epidemiological principles in dental caries attack. Bulletin of Tokyo Dental Colloquium 3: 96-111.

Tannure PN, Küchler EC, Falagan-Lotsch P, Amorim R. Raggio Luiz LMF, Costa MC, Vieira AR, Granjeiro JM. 2012. MMP13 polymorphism decreases risk for dental caries. Caries Research 46:401-407.

Tayles N, Domett K, Nelsen K. 2000. Agriculture and dental caries? The case of rice in southeast Asia. World Archaeology 32(1):68-83.

Techanitiswad T. 1994. Determinants of the variation in dental caries of 2- and 4-year-old Thai children in an urban area of Khon Kaen Province, northeastern Thailand. PhD dissertation, University of Otago, Dunedin.

Thompson WM, Poulton R, Milne BJ, Caspi A, Broughton JR, Ayers KMS. 2004. Socioeconomic inequalities in oral health in childhood and adulthood in a birth cohort. Community Dentistry and Oral Epidemiology 32:345-353.

Thompson AH, Richards MP, Shortland A, Zakrzewski SR. 2005. Isotopic paleodiet studies of ancient Egyptian fauna and humans. Journal of Archaeological Science 32:451-463.

Thornton F. 1991. Dental disease in a Romano-British population from Baldock, Hertfdordshire. International Journal of Osteoarchaeology 1:273-277.

Touger-Decker R, van Loveren C. 2003. Sugar and dental caries. American Journal of Clinical Nutrition 78 (suppl):881S-892S.

Trigger BG. 1976. Kerma: The rise of an African civilization. The International Journal of African Historical Studies 9(1):1-21.

Turner II CG. 1978. Dental caries and early Equadorian agriculture. American Antiquity 43(4):694-697.

Turner II CG. 1979: Dental anthropological indications of agriculture among the Jomon people of Central Japan. American Journal of Physical Anthropology 51:619-636.

Turner II CG. 1987. Late Pleistocene and Holocene population history of east Asia based on dental variation. American Journal of Physical Anthropology 73:305-321.

Usai D, Salvatori S. 2008. The Late Paleolithic-Mesolithic-Neolithic and post-Meroitic cemetery of al Khiday 2, the associated Mesolithic settlement of al Khidai 1, and the post-Meroitic cemetery 16-C-2, Central Sudan. Rome: Instituto Italiano per l' Africa e l' Oriente.

Van der Merwe NJ. 1992. Light stable isotopes and the reconstruction of prehistoric diets. Proceedings of the British Academy 77:247-264.

Van der Veen M. 1995. Ancient agriculture in Libya: A review of the evidence. Acta Paleobotanica 35(1):85-98.

Van Gerven DP, Sheridan SG, Adams WY. 1995. The health and nutrition of a medieval Nubian population: The impact of political and economic change. American Anthropologist, New Series, 97(3):468-480.

Van Houte J. 1980. Bacterial specificity in the etiology of dental caries. International Dental Journal 30: 305-326.

Van Houte. 1994. Role of microorganisms in caries etiology. Journal of Dental Research 73:672-681.

Van Neer W. 1989. Fishing along the prehistoric Nile. In: Krzyzaniak L, Kobusiewitz M, editors. Late Prehistory of the Nile Basin and the Sahara. Poznan Archaeological Museum. p 49-56.

Van Neer W, Linseele V. 2002. New analyses of old bones: The faunal remains from Hierankopolis. Friends of Nekhen 14:7-8.

Van Peer P, Fulagar R, Stokes S, Bailey RM, Moeyersons J, Steenhound F, Geertz A, Vanderbeken T, De Capper M, Geus F. 2003. The Early to Middle Stone Age transition and the emergence of modern human behavior at site 8-B-11, Sai Island, Sudan. Journal of Human Evolution 45:187-193.

Vieira AR, Marazita ML, Goldstein-McHenry T. 2008. Genome-wide scan finds suggestive caries loci. Journal of Dental Research 87(5):435-439.

Vodanovic M, Hrvoje B, Mario S, Zeljko D. 2005. The frequency and distribution of caries in the medieval population of Bijelo Brdo in Croatia ($10^{th}$-$11^{th}$ century). Archives of Oral Biology 50:669-680.

Vyhnanek L, Strouhal E, Nemeckova A. 1999.'Kissing' osteochondroma: A case from ancient Egypt. International Journal of Osteoarchaeology 9:361-368.

Walker PL, Erlandson JM. 1986. Dental evidence for prehistoric dietary change on the northern Channel islands, California. American Antiquity 51(2):375-383.

Walker PL, Hewlett BS. 1990. Dental health diet and social status among central African foragers and farmers. American Anthropologist 92(2):383-398.

Wasylikowa K, Dahlberg J. 1999. Sorghum in the economy of the early Neolithic tribes at Nabta Playa, southern Egypt. In: van der Veen M, editor. The Exploitation of Plant Resources in Ancient Africa. p 11-32.

Wendorf F. 1968. Site 117: A Nubian Final Paleolithic graveyars near Jebel Sahaba, Sudan. In: Wendorf F, editor. The Prehistory of Nubia. Dallas: Fort Burgwin Research Center. p 954-995.

Wendorf F. 1980a. Human exploitation of the western desert. In: Wendorf F, Schild R, editors. Prehistory of the Eastern Sahara. Academic Press. p 243-272.

Wendorf F. 1980b. Paleoenvironment of the western desert of Egypt. In: Wendorf F, Schild R, editors. Prehistory of the Eastern Sahara. Academic Press. p 223-241.

Wendorf F, Schild R. 1976. The use of ground grain during the Late Paleolithic of the lower Nile Valley, Egypt. In: Harlan JR, De Wet JMJ, Stemier ABL, editors. Origins of African Plant Domestication. The Hague: Mutton. p 269-288.

Wendorf F, Schild R, Said R, Haynes VC, Gautier A, Kobusiewitz M. 1976. The prehistory of the eastern Sahara. Science 193:103-114.

Wendorf F, Hassan FA. 1980. Holocene ecology and prehistory in the Sahara. In: Williams MAJ, Faure H, editors. The Sahara and the Nile. Rotterdam: p 407-419.

Wendorf F, Schild R. 1984. Some implications of Late Paleolithic cereal exploitation at Wadi Kubbaniya (Upper Egypt). In: Krzyzaniak L, Kobusiewitz M, editors. Origin and Early Development of Foof Producing Cultures in North-East Africa. Poznan Arcaheological Museum. p 117-127.

Wendorf F, Close AE, Schild R, Wasylikowa K, Housleys RA, Harlan JR, Królik H. 1992. Saharan exploitation of plants 8,000 years BP. Nature 359:721-724.

Wendorf F, Schild R. 1994. Are the early Holocene cattle in the eastern Sahara domestic or wild? Evolutionary Anthropology 3:118-129.

Wendorf F, Schild R. 2001. Introduction. In: Wendorf F, Schild R, editors. Holocene Settlement of the Egyptian Sahara. Volume 1: The Archaeology of Nabta Playa. Kluwer Academic/Plenum. p 1-10.

Wenke RJ. 1989. Egypt: Origins of complex societies. Annual Review of Archaeology 18:129-155.

Wenke RJ, Long JE, Buck PE. 1988. Epipaleolithic and Neolithic subsistence and settlement in the Fayyum Oasis of Egypt. Journal of Field Archaeology 15(1):29-51.

Wenke RJ, Casini M. 1989. The Epipaleolithic-Neolithic transition in Egypt's Fayum Depression. In: Krzyzaniak Lech, Kobusiewitz Michal, editors. Late Prehistory of the Nile Basin and the Sahara. Poznan Archaeological Museum. p139-155.

Wetterstrom W. 1993a. Foraging and farming in Egypt: The transition from hunting and gathering to horticulture in the Nile Valley. In: Shaw T, Sinclair P, Andah Okpoko A, editors. The Archaeology of Africa: Food, Metal, and Towns. London: Routledge. p 165-226.

Wetterstrom W. 1993b. The origins of agriculture in Africa: With particular reference to sorghum and pearl millet. The Review of Archaeology 19(2):30-46.

Wetterstrom W. 1997. Nile Valley: Pre-agricultural cultures. In: Vogel JO, editor. Encyclopedia of Precolonial Africa: Archaeology, History, Language, Cultures, and Environment. Walnut Creek, CA: Alta Mira Press. p 386-388.

White CD, Longstaffe FJ, Law KR. 1999. Seasonal stability and variation in diet as reflected in human mummy tissues from the Kharga Oasis in the Nile Valley. Paleogeography, Paleoclimatology, Paleoecology 147:209-222.

Whittaker DK, Molleson T, Bennett RB, Edwards I, Jenkins PR, Llewelyn JH. 1981. The prevalence and distribution of dental caries in a Romano-British population. Archives of Oral Biology 26:237-245.

Williams B. 1997. Egypt and sub-Saharan Africa: Their interaction. In: Vogel JO, editor. Encyclopedia of Precolonial Africa. Archaeology, History, Language, Cultures, and Environment. London:Alta Mira Press. p 465-472.

Wilkins A, Barnard H, Rose PJ. 2006. Roman artillery balls from Qasr Ibrim, Egypt. Sudan and Nubia 10:66-80.

Zakrzewski SR. 2007. Population continuity or population change: Formation of the ancient Egyptian state. American Journal of Physical Anthropology 132:501-509.

Zita A, McDonald RE, Andrews AL. 1959. Dietary habits and the dental caries experience in 200 children. Journal of Dental Research 38: 860-865.

## Appendix A

**Table A1:** *T*-test results for the variable Country.

| | Egypt | Nubia | p value (Sig.) | Eta$^2$ |
|---|---|---|---|---|
| **No. of teeth** | 14,696 | 11,500 | | |
| **n** | 1019 | 734 | | |
| **Tooth caries** | 2.20% | 1.40% | | |
| **Mean tooth caries** | 0.3* | 0.2* | 0.005* | 0.004 |
| **Indiv. caries** | 16.60% | 11.80% | | |
| **Mean caries/indiv.** | 2.5 | 1.9 | 1.39 | 0.001 |
| **AMTL** | 6.30% | 6.90% | | |
| **Mean AMTL** | 0.9 | 1 | 0.172 | 0.001 |
| * significant at 0.05 level | | | | |
| ^ significant at .008 level (Bonferroni) | | | | |

**Table A2:** ANOVA results for the variable Region

| | Lower Egypt | Upper Egypt | Lower Nubia | Upper Nubia | p value (Sig.) | Eta$^2$ |
|---|---|---|---|---|---|---|
| **No. teeth** | 4,285 | 10,411 | 7,565 | 3,935 | | |
| **n** | 312 | 753 | 499 | 278 | | |
| **Tooth caries** | 3.7% | 1.6% | 1% | 2% | | |
| **Mean tooth caries** | 0.5* | 0.2 ^ | 0.15^ | 0.3^ | 0.000 | 0.021 |
| **Indiv. caries** | 23.9% | 13.5% | 9% | 17.8% | | |
| **Mean caries/indiv.** | 0.6* | 0.4 | 0.5 | 0.3^ | 0.001 | 0.009 |
| **AMTL** | 8.8% | 5% | 7.2% | 6.2% | | |
| **Mean AMTL** | 1.2^ | 0.7* | 1^ | 0.9 | 0.003 | 0.007 |
| * is significantly different from ^ at 0.05 level | | | | | | |
| Bonferroni correction = 0.004 | | | | | | |

**Table A3:** ANOVA results for the variable Economy

| | Preagricultural | Agricultural | Intense Agricult | p value (Sig) | Eta$^2$ |
|---|---|---|---|---|---|
| **No. teeth** | 3,533 | 15,595 | 7,068 | | |
| **n** | 231 | 1153 | 457 | | |
| **Tooth caries** | 1.00% | 1.90% | 2.10% | | |
| **Mean tooth caries** | 0.16^ | 0.25 | 0.34* | 0.24* | 0.004 |
| **Individual caries** | 10.40% | 15% | 14.20% | | |
| **Mean caries/indiv.** | 1.6 | 2.3 | 2.4 | 0.376 | 0.001 |
| **AMTL** | 4.30% | 6.20% | 8.50% | | |
| **Mean AMTL** | 0.65^ | 0.8^ | 1.3* | 0.000*# | 0.01 |
| * is significantly higher than ^ at .05 level | | | | | |
| # significant at 0.005 level (Bonferroni) | | | | | |

**Table A4:** ANOVA results for the variable Period

| Period | n | Tooth caries | Mean tooth caries | Individual caries | Mean caries/indiv. | AMTL | Mean AMTL |
|---|---|---|---|---|---|---|---|
| **Prehistoric** | 231 | 1.00% | 0.16^ | 10.40% | 1.6 | 4.30% | $0.6^{ACD}$ |
| **Predynastic** | 414 | 1.40% | 0.19^ | 11.60% | 1.5^ | 3.20% | $0.4^{ABCD}$ |
| **Early Nubian** | 162 | 2.60% | 0.35 | 18.50% | 3.9 | 3.70% | $0.5^{ABCD}$ |
| **Dynastic** | 346 | 1.80% | 0.24 | 14.70% | 1.8 | 8.70% | $1.2^{D}$ |
| **Classic Nubian** | 233 | 1.90% | 0.25 | 15.40% | 2.9 | 9.60% | $1.3^{C}$ |
| **Late Dynastic** | 257 | 3.20% | 0.48* | 20.20% | 3.2* | 7.40% | $1.1^{B}$ |
| **Late Nubian** | 199 | 1.40% | 0.22 | 10.10% | 1.7 | 9.80% | $1.5^{A}$ |
| **p value** | | | .000*# | | .002*# | | .000*# |
| **Eta$^2$** | | | 0.15 | | 0.12 | | 0.031 |
| * is significantly different from * and ^, α = .05. * also indicates significant p value at .05 level. | | | | | | | |
| # significant at .002 level (Bonferroni) | | | | | | | |
| A, B, C, and D are significantly different with earlier periods but not all, α = 0.05 | | | | | | | |

**Table A5:** Sex comparison results for Country (*T*-test).

| | Egypt | | Nubia | |
|---|---|---|---|---|
| | Males | Females | Males | Females |
| **n** | 395 | 457 | 281 | 336 |
| **Tooth caries** | 47.92% | 52.08% | 43.50% | 56.50% |
| **Mean tooth caries** | .34 | .38 | .20 | .26 |
| **p value** | .654 | | .313 | |
| **Eta$^2$** | .000 | | .002 | |
| **Indiv. caries** | 17.50% | 18.60% | 15.10% | 13.30% |
| **Mean caries/Indiv.** | 2.5 | 3.1 | 2.1 | 2 |
| **p value** | .307 | | .907 | |
| **Eta$^2$** | .001 | | .00003 | |
| **AMTL** | 53.30% | 46.70% | 48.80% | 51.20% |
| Bonferroni correction = .01 | | | | |

**Table A6:** Sex comparison results for Region (*T*-tests).

| | Lower Egypt | | Upper Egypt | | Lower Nubia | | Upper Nubia | |
|---|---|---|---|---|---|---|---|---|
| | **Males** | **Females** | **Males** | **Females** | **Males** | **Females** | **Males** | **Females** |
| **n** | 135 | 142 | 260 | 315 | 188 | 220 | 93 | 117 |
| **Tooth caries** | 57.9% | 42.1% | 36.8% | 63.2% | 37.8% | 62.2% | 49.5% | 50.5% |
| **Mean tooth caries** | 0.63 | 0.46 | 0.2 | 0.34 | 0.13 | 0.2 | 0.34 | 0.35 |
| **p value** | 0.248 | | 0.032* | | 0.213 | | 0.956 | |
| **Eta$^2$** | 0.005 | | 0.012 | | 0.003 | | 0.012 | |
| **Indiv. caries** | 29.6% | 19.0% | 11.1% | 18.4% | 8.0% | 11.5% | 23.7% | 18.4% |
| **Mean caries/indiv.** | 4.2 | 3.5 | 1.6 | 2.9 | 1.2 | 1.6 | 4 | 2.8 |
| **p value** | 0.501 | | 0.047* | | 0.44 | | 0.42 | |
| **Eta$^2$** | 0.001 | | 0.01 | | 0.031 | | 0.003 | |
| **AMTL** | 57% | 43% | 50% | 50% | 49.30% | 50.70% | 47% | 53% |
| * significant at 0.05 level | | | | | | | | |
| ^ significant at .008 (Bonferroni) | | | | | | | | |

**Table A7:** Sex comparison results for Economy

| | Preagricultural | | Agricultural | | Intense Agricultural | |
|---|---|---|---|---|---|---|
| | **Males** | **Females** | **Males** | **Females** | **Males** | **Females** |
| **n** | 78 | 94 | 417 | 487 | 181 | 212 |
| **Tooth caries** | 54.70% | 45.30% | 43.50% | 56.50% | 50.20% | 49.80% |
| **Mean tooth caries** | 0.23 | 0.2 | 0.25 | 0.33 | 0.38 | 0.37 |
| **p value (Sig.)** | 0.693 | | 0.148 | | 0.978 | |
| **Eta$^2$** | 0.0001 | | 0.002 | | 0.003 | |
| **Indiv. caries** | 16.70% | 10.60% | 14.90% | 18.70% | 17.10% | 13.70% |
| **Mean caries/indiv.** | 3.3 | 0.8 | 2.2 | 2.3 | 2.4 | 2.6 |
| **p value (Sig.)** | 0.048* | | 0.114 | | 0.83 | |
| **Eta$^2$** | 0.012 | | 0.0046 | | 0.0024 | |
| **AMTL** | 9.70% | 13.40% | 16.10% | 14.10% | 23.40% | 23.30% |
| **p value (Sig.)** | 0.381 | | 0.389 | | 98.80% | |
| **Eta$^2$** | 0.0014 | | 0.005 | | 0.004 | |
| * significant at 0.05 level | | | | | | |
| ^ significant at .008 level (Bonferroni) | | | | | | |

**Table A8:** Sex comparison results for Period

| Period | n | | Mean tooth caries | | p value (Sig) | Eta$^2$ |
|---|---|---|---|---|---|---|
| | **M** | **F** | **M** | **F** | | |
| **Prehistoric** | 78 | 94 | 0.23 | 0.2 | 0.693 | 0.0009 |
| **Predynastic** | 116 | 166 | 0.2 | 0.3 | 0.734 | 0.001 |
| **Early Nubian** | 51 | 86 | 0.2 | 0.5 | 0.057 | 0.003 |
| **Dynastic** | 157 | 141 | 0.25 | 0.26 | 0.934 | 0.023 |
| **Classic Nubian** | 84 | 97 | 0.2 | 0.3 | 0.393 | 0.001 |
| **Late Dynastic** | 108 | 124 | 0.6 | 0.5 | 0.593 | 0.011 |
| **Late Nubian** | 82 | 85 | 0.2 | 0.3 | 0.439 | 0.003 |
| | **n** | | **Mean caries/indiv.** | | | |
| | **M** | **F** | **M** | **F** | | |
| **Prehistoric** | 78 | 94 | 3.2 | 0.8 | 0.056 | 0.022 |
| **Predynastic** | 116 | 166 | 1.9 | 2.1 | 0.698 | 0.0005 |
| **Early Nubian** | 51 | 86 | 2.4 | 5 | 0.173 | 0.014 |
| **Dynastic** | 157 | 141 | 1.9 | 2 | 0.951 | .0001 |
| **Classic Nubian** | 84 | 97 | 2.4 | 3.7 | 0.381 | 0.004 |
| **Late Dynastic** | 108 | 124 | 3.4 | 3.3 | 0.935 | .000 |
| **Late Nubian** | 82 | 85 | 1.4 | 2 | 0.565 | 0.002 |

| | n | | AMTL | | p value (Sig) | Eta$^2$ |
|---|---|---|---|---|---|---|
| | M | F | M | F | | |
| **Prehistoric** | 78 | 94 | 61.9% | 38.1% | 0.381 | 0.004 |
| **Predynastic** | 116 | 166 | 39.4% | 60.6% | 0.211 | 0.005 |
| **Early Nubian** | 51 | 86 | 63.4% | 36.6% | 0.261 | 0.009 |
| **Dynastic** | 157 | 141 | 45.4% | 54.6% | 0.434 | 0.002 |
| **Classic Nubian** | 84 | 97 | 61.9% | 38.1% | 0.139 | 0.012 |
| **Late Dynastic** | 108 | 124 | 67.6% | 32.9% | 0.005* | 0.0346 |
| **Late Nubian** | 82 | 85 | 35.8% | 64.2% | 0.051 | 0.023 |
| * significant at .05 level | | | | | | |
| ^ significant at .002 level (Bonferroni) | | | | | | |

**Table A9:** ANOVA results for Status

| Social Status | Lower | Middle | Upper |
|---|---|---|---|
| **n** | 312 | 134 | 491 |
| **Tooth caries** | 25.00% | 20.50% | 54.50% |
| **Mean tooth caries** | 0.17^ | 0.14^ | 0.4* |
| **p value** | .001*^ | | |
| **Eta$^2$** | 0.008 | | |
| **Indiv. caries** | 10.30% | 8.20% | 18.30% |
| **Mean caries/indiv.** | 1.3^ | 1.0^ | 2.8* |
| **p value** | .010* | | |
| **Eta$^2$** | 0.005 | | |
| **AMTL** | 12.5%* | 31.7%* | 55.8%* |
| Bonferroni correction = .005 | | | |
| * is higher than ^ among samples at .05 level | | | |
| all samples have significantly different AMTL with each other | | | |

# Appendix B

**Table B1:** Mann-Whitney results for Region.

| Region | | Tooth caries | | Individual caries | | AMTL | |
|---|---|---|---|---|---|---|---|
| | n | Mean rank | Asympt. Sig. | Mean rank | Asympt. Sig. | Mean rank | Asympt. Sig. |
| Lower Egypt | 312 | 574.9 | .000*^ | 547.9 | .000*^ | 574.2 | .000*^ |
| Upper Egypt | 752 | 515.2 | | 493 | | 515.2 | |
| | | | | | | | |
| Lower Egypt | 312 | 443.2 | .000*^ | 419.9 | .000*^ | 421.2 | .072 |
| Lower Nubia | 499 | 382.8 | | 363.7 | | 396.5 | |
| | | | | | | | |
| Lower Egypt | 312 | 305.07 | .040* | 297 | .052 | 302 | .237 |
| Upper Nubia | 278 | 284.8 | | 277.8 | | 288.2 | |
| | | | | | | | |
| Upper Egypt | 752 | 635.9 | .031* | 598.2 | .040* | 613.8 | .057 |
| Lower Nubia | 465 | 611.2 | | 574.9 | | 644.3 | |
| | | | | | | | |
| Upper Egypt | 752 | 509.7 | .071 | 485.3 | | 505.7 | .024 |
| Upper Nubia | 278 | 532.1 | | 505.9 | .098 | 541.9 | |
| | | | | | | | |
| Lower Nubia | 499 | 377.4 | .001*^ | 356.5 | 0.001*^ | 386.4 | .590 |
| Upper Nubia | 278 | 409.9 | | 386.6 | | 393.7 | |
| * significant at .05 level | | | | | | | |
| ^ significant at .008 level (Bonferroni) | | | | | | | |

**Table B2:** Mann-Whitney results for Economy

| Economy | | Tooth caries | | Individual caries | | AMTL | |
|---|---|---|---|---|---|---|---|
| | n | Mean rank | Asympt. Sig. | Mean rank | Asympt. Sig. | Mean rank | Asympt. Sig. |
| Preagricult. | 231 | 665.5 | .064 | 631.5 | .094 | 677.1 | .399 |
| Agricultural | 1153 | 697.9 | | 661.5 | | 695.6 | |
| | | | | | | | |
| Preagricult. | 231 | 334.6 | .113 | 316.6 | .187 | 313.2 | .000*^ |
| Intense agric. | 457 | 349.5 | | 329 | | 360.3 | |
| | | | | | | | |
| Agricultural | 1153 | 806 | .917 | 773 | .816 | 780.5 | .000*^ |
| Intense agric. | 457 | 804.3 | | 769.4 | | 868.5 | |
| * significant at .05 level | | | | | | | |
| ^ significant at .005 level (Bonferroni) | | | | | | | |

**Table B3:** Mann-Whitney results for Period

| Period | | Tooth caries | | Individual caries | | AMTL | |
|---|---|---|---|---|---|---|---|
| | n | Mean rank | Asympt. Sig. | Mean rank | Asympt. Sig. | Mean rank | Asympt. Sig. |
| Prehistoric | 231 | 319.8 | .609 | 294.6 | .657 | 338.6 | .015 |
| Predynastic | 413 | 324 | | 298.3 | | 313.5 | |
| | | | | | | | |
| Prehistoric | 231 | 190.1 | 0.016 | 173 | .015 | 201.1 | .228 |
| Early Nubian | 162 | 206.4 | | 189.8 | | 191.1 | |
| | | | | | | | |
| Prehistoric | 231 | 281.4 | .123 | 267.9 | .202 | 268.8 | 0.003 |
| Dynastic | 346 | 294.1 | | 278.5 | | 302.5 | |
| | | | | | | | |
| Prehistoric | 231 | 226.5 | .098 | 214.6 | .156 | 215.3 | 0.001 |
| Classic Nubian | 233 | 238.5 | | 224.9 | | 249.5 | |
| | | | | | | | |
| Prehistoric | 231 | 230.9 | 0.001 | 219.1 | | 228.6 | 0.003 |
| Late Dynastic | 257 | 256.7 | | 241.7 | 0.005 | 258.7 | |
| | | | | | | | |
| Prehistoric | 231 | 215.6 | .982 | 198.5 | 0.907 | 201.9 | 0.002 |
| Late Nubian | 199 | 215.4 | | 198.1 | | 231.3 | |
| | | | | | | | |
| Predynastic | 413 | 282.2 | 0.024 | 261.4 | 0.017 | 286 | .464 |
| Early Nubian | 162 | 302.8 | | 283.1 | | 293.2 | |
| | | | | | | | |
| Predynastic | 413 | 374.7 | .213 | 357.6 | .315 | 346.9 | .000 |
| Dynastic | 346 | 386.3 | | 367 | | 419.5 | |
| | | | | | | | |
| Predynastic | 413 | 319 | .166 | 303.5 | .224 | 297.1 | .000 |
| Clasic Nubian | 233 | 331.4 | | 370.2 | | 370.2 | |
| | | | | | | | |
| Predyanstic | 413 | 323.6 | .001 | 308 | .003 | 309.6 | .000 |
| Late Dynastic | 257 | 354.6 | | 335.6 | | 377.2 | |
| | | | | | | | |
| Predynastic | 413 | 307.8 | .618 | 287.4 | .610 | 285.5 | .000 |
| Late Nubian | 199 | 303.7 | | 283.2 | | 350 | |
| | | | | | | | |
| Early Nubian | 162 | 261.8 | .231 | 254.7 | .120 | 226 | .000 |
| Dynastic | 346 | 251.1 | | 240.7 | | 267.9 | |
| | | | | | | | |
| Early Nubian | 162 | 202 | .370 | 195.8 | .252 | 175 | .000 |
| Classic Nubian | 233 | 195.2 | | 187 | | 214 | |

| Period | | Teeth caries | | Individual caries | | AMTL | |
|---|---|---|---|---|---|---|---|
| Early Nubian | 162 | 207 | .566 | 201.5 | .920 | 187.7 | .000 |
| Late Dynastic | 257 | 211.9 | | 202.3 | | 224 | |
| | | | | | | | |
| Early Nubian | 162 | 189.3 | 0.023 | 177.7 | 0.017 | 162.6 | .000 |
| Late Nubian | 199 | 174.3 | | 162 | | 200 | |
| | | | | | | | |
| Dynastic | 346 | 289.1 | .799 | 283.9 | .755 | 287 | .533 |
| Classic Nubian | 233 | 291.3 | | 286.6 | | 294.5 | |
| | | | | | | | |
| Dynastic | 346 | 293.8 | .041 | 288.7 | .053 | 301.6 | .948 |
| Late Dynastic | 257 | 313 | | 306.9 | | 302.5 | |
| | | | | | | | |
| Dynastic | 346 | 277.3 | .146 | 267.2 | .206 | 270.7 | .599 |
| Late Nubian | 199 | 265.4 | | 256.6 | | 277 | |
| | | | | | | | |
| Classic Nubian | 233 | 238.3 | .107 | 235.7 | .157 | 248.6 | .596 |
| Late Dynastic | 257 | 252 | | 247.8 | | 242.7 | |
| | | | | | | | |
| Classic Nubian | 233 | 221.6 | .115 | 213.5 | .150 | 216.9 | .929 |
| Late Nubian | 199 | 210.5 | | 203.4 | | 216 | |
| | | | | | | | |
| Late Dynastic | 257 | 238.8 | 0.003 | 229.7 | 0.006 | 226.5 | .672 |
| Late Nubian | 199 | 215.2 | | 208 | | 231 | |
| Bonferroni correction = .002 | | | | | | | |

**Table B4:** Mann-Whitney results for dental caries and Sex by Country.

| Egypt | | | | |
|---|---|---|---|---|
| | Sex | n | Mean Rank | Asympt. Sig. |
| Tooth caries | Male | 380 | 407.31 | |
| | Female | 431 | 404.85 | |
| | Total | 811 | | 0.82 |
| Caries/indiv. | Male | 376 | 398.3 | |
| | Female | 419 | 397.73 | |
| | Total | 795 | | 0.958 |
| AMTL | Male | 380 | 417.13 | |
| | Female | 431 | 396.18 | |
| | Total | 811 | | 0.119 |
| **Nubia** | | | | |
| Tooth caries | Male | 295 | 324.63 | |
| | Female | 363 | 333.46 | |
| | Total | 658 | | 0.338 |
| Caries/indiv. | Male | 290 | 318.96 | |
| | Female | 356 | 327.2 | |
| | Total | 646 | | 0.371 |
| AMTL | Male | 295 | 337.33 | |
| | Female | 363 | 323.13 | |
| | Total | 658 | | 0.246 |
| * significant at .05 level | | | | |
| ^ significant at .008 (Bonferroni) | | | | |

**Table B5:** Mann Whitney results for dental caries and Sex by Region

| | **Lower Egypt** | | **Upper Egypt** | | **Lower Nubia** | | **Upper Nubia** | |
|---|---|---|---|---|---|---|---|---|
| | **Males** | **Females** | **Males** | **Females** | **Males** | **Females** | **Males** | **Females** |
| **n** | 135 | 142 | 259 | 315 | 188 | 220 | 93 | 117 |
| **Mean ranks t/c** | 145.97 | 132.38 | 276 | 296.9 | 201.29 | 207.24 | 108.42 | 103.18 |
| **Asympt. Sig.** | 0.6 | | 0.016* | | 0.319 | | 0.378 | |
| **Mean ranks c/i** | 142.27 | 130.81 | 269.16 | 290.86 | 197.38 | 203.16 | 107.99 | 101.73 |
| **Asympt. Sig** | 0.112 | | 0.012* | | 0.333 | | 0.293 | |
| **Mean ranks AMTL** | 147.82 | 130.62 | 289.28 | 286.04 | 210.76 | 199.15 | 105.82 | 105.25 |
| **Asympt. Sig.** | 0.037* | | 0.769 | | 0.223 | | 0.936 | |
| * significant at 0.05 level | | | | | | | | |
| ^ significant at .008 (Bonferroni) | | | | | | | | |

**Table B6:** Mann-Whitney results for dental caries and Sex by Economy.

| | Preagricultural | | Agricultural | | Intense Agricultural | |
|---|---|---|---|---|---|---|
| | Males | Females | Males | Females | Males | Females |
| n | 78 | 94 | 416 | 488 | 181 | 212 |
| Mean ranks t/c | 89.29 | 84.18 | 443.16 | 460.46 | 200.18 | 194.29 |
| Asympt. Sig. | .256 | | .128 | | .412 | |
| Mean ranks c/i | 87.25 | 81.35 | 433.00 | 451.67 | 197.66 | 192.71 |
| Asympt. Sig. | .191 | | .100 | | .491 | |
| Mean ranks AMTL | 84.88 | 87.85 | 464.62 | 442.17 | 204.87 | 190.28 |
| Asympt. Sig. | .614 | | .104 | | .149 | |
| * significant at 0.05 level | | | | | | |
| ^ significant at .008 level (Bonferroni) | | | | | | |

**Table B7:** Mann-Whitney results for dental caries and Sex by Period.

| Period | n | | Mean ranks t/c | | Asympt. Sig. |
|---|---|---|---|---|---|
| | M | F | M | F | |
| Prehistoric | 78 | 94 | 89.29 | 84.18 | 0.256 |
| Predynastic | 115 | 166 | 139.68 | 141.92 | 0.719 |
| Early Nubian | 51 | 87 | 63.54 | 72.99 | 0.056 |
| Dynastic | 157 | 141 | 147.67 | 151.54 | 0.529 |
| Classic Nubian | 84 | 97 | 89.81 | 92.03 | 0.66 |
| Late Dynastic | 108 | 124 | 120.84 | 112.72 | 0.201 |
| Late Nubian | 82 | 85 | 83.62 | 84.36 | 0.85 |
| | n | | Mean ranks caries/indiv. | | |
| | M | F | M | F | |
| Prehistoric | 75 | 92 | 87.25 | 81.35 | 0.191 |
| Predynastic | 116 | 166 | 134.58 | 137 | 0.697 |
| Early Nubian | 50 | 84 | 61.53 | 71.05 | 0.053 |
| Dynastic | 156 | 139 | 145.87 | 150.39 | 0.463 |
| Classic Nubian | 83 | 97 | 89.51 | 91.35 | 0.717 |
| Late Dynastic | 108 | 121 | 118.78 | 111.62 | 0.259 |
| Late Nubian | 82 | 83 | 82.4 | 83.59 | 0.762 |
| | n | | Mean ranks AMTL | | |
| | M | F | M | F | |
| Prehistoric | 78 | 94 | 84.88 | 87.85 | 0.614 |
| Predynastic | 116 | 166 | 138.57 | 142.68 | 0.561 |
| Early Nubian | 51 | 87 | 71.85 | 68.12 | 0.438 |
| Dynastic | 157 | 141 | 147.93 | 151.24 | 0.694 |
| Classic Nubian | 84 | 97 | 97.41 | 85.45 | 0.076 |
| Late Dynastic | 108 | 124 | 129.26 | 105.38 | .002*^ |
| Late Nubian | 82 | 85 | 81.65 | 86.26 | 0.488 |

**Table B8:** Mann-Whitney results for Status.

| Social Status | | Tooth caries | | Individual caries | | AMTL | |
|---|---|---|---|---|---|---|---|
| | n | Mean rank | Asympt. Sig. | Mean rank | Asympt. Sig. | Mean rank | Asympt. Sig. |
| Lower | 311 | 224.36 | .507 | 212.23 | .413 | 211.94 | .000*^ |
| Middle | 134 | 219.84 | | 206.73 | | 248.66 | |
| | | | | | | | |
| Lower | 311 | 381.25 | 0.002*^ | 363.44 | 0.0038^ | 341.6 | .000*^ |
| Upper | 491 | 414.32 | | 394.81 | | 439.44 | |
| | | | | | | | |
| Middle | 134 | 287.95 | 0.005*^ | 279.68 | 0.004*^ | 290.42 | .052 |
| Upper | 491 | 319.84 | | 312.01 | | 319.16 | |
| * significant at .05 level | | | | | | | |
| ^ significant at .005 (Bonferroni) | | | | | | | |

**Appendix C**

From: Konstantine Triambelas [ktriambelas@alaska.edu]
Sent: Saturday, March 15, 2014 10:46 PM
To: Irish, Joel
Subject: re: urgent but VERY simple, please read

Hello Dr. Irish, I need your permission to use Figure 1 in my thesis (your map from Irish and Friedman 2010). Please send me an email so I can attach it to the thesis.

Most sincerely, Konstantine.

Konstantine: I give you permission to use my map from Irish and Friedman 2010 in your Figure 1. Joel D. Irish

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
Professor Joel D. Irish, Ph.D.
Research Centre in Evolutionary Anthropology and Palaeoecology
School of Natural Sciences and Psychology
Liverpool John Moores University
Byrom Street
Liverpool L3 3AF
United Kingdom

+44 (0)151 231 2387 (Office)
+44 (0)151 231 2290 (Lab)
+44 (0)151 231 2338 (Fax)
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~